INTRODUCTORY GENERAL SCIENCE

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PHYSICS, CHEMISTRY AND BIOLOGY

WITH SUGGESTIONS FOR PRACTICAL WORK

BY

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AND

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PREFACE

FOR many years, Physics and Chemistry have been the chief science subjects studied in Secondary Schools; and the courses followed have usually been those prescribed by university and other examining authorities. It has, however, been urged for some time that the range of school science courses should be extended, particularly in the field of studies of plant and animal life, including man and his relationships to them. This view has led to developments in two directions: one in the introduction of Biology—the science of life—and the other in extending the scope still further so as to cover all common natural objects and phenomena to which young students are likely to give attention, and a preliminary knowledge of which would give them intelligent interest, not only in Nature's ways, but also in man's uses and control of them.

It is obvious that to draw up any scheme of general elementary science of this kind is very difficult. The result is that though examining bodies, and organisations of teachers and committees reporting on the subject, have suggested courses of work for schools, no general agreement has yet been reached as to what such courses should include or exclude. The principle is accepted that the outlook of school science should be extensive, and not specialised or intensive; but how best to put this into practice has not yet been decided.

Several considerations have to be borne in mind when a university or any other authority prepares a scheme of Elementary General Science for schools. In the first place, the success of a scheme must depend upon the teachers themselves and the equipment with which they are provided for scientific instruction in it. As most of the science teaching in Secondary Schools has, for a long time, been limited to the rudiments of Physics and Chemistry, the introduction

of biological subjects must be a slow process and can be undertaken only when teachers competent to give instruction in it are available.

These subjects must, however, be included in any course of General Science, whatever other aspects of Nature are represented in it ; and in most schools they will be taught by teachers who have given special attention to the sciences of life rather than to those of matter and motion. It is not an ideal plan to keep these branches of science in separate compartments in courses of General Science, but under existing conditions the instruction will be given in many schools by different teachers. On this account, Physics, Chemistry and the life sciences are, in the present book, dealt with in three separate Parts, each of which is self-contained so far as it goes. The Parts are published separately as well as together, and each thus provides an introductory course in Physics, Chemistry or Biology.

The division of General Science into several sections representing physics, chemistry and the biological sciences is adopted in the syllabus prescribed for matriculation by the University of Bombay. The subject is optional with four other science subjects, but as the scope is so extensive, the standard of attainment expected of students must evidently be much lower. The main idea is to provide an elementary knowledge of a wide range of subjects rather than detailed or specialised training in one particular branch of science. The Bombay syllabus therefore includes elements of physiology, botany, zoology and hygiene in addition to those of physics and chemistry. In dealing with those aspects of the life sciences in the present book, an endeavour has been made to show how structures, functions and processes in plant and animal life have many relationships in common ; while an understanding of the chief of them depends upon an acquaintance with the elementary principles of physics and chemistry.

A knowledge in outline of all these aspects of science is regarded as essential in every course of General Science. In this respect, therefore, the syllabus for General Science of the Board of High School and Intermediate Education of the United Provinces, and that of Elementary Scientific Knowledge of the Calcutta University

Matriculation Examination, are on much the same lines as those of the Bombay course, and are covered in this volume. The Calcutta syllabus prescribes, in addition, an elementary knowledge of astronomical and geological objects and phenomena, which may be included very appropriately in a General Science course but do not fit easily into a scheme of work limited to Physics, Chemistry and Biology.

It cannot be expected that every student will perform all the observational and experimental work for which instructions are given at the ends of the chapters of the book. Teachers should decide for themselves what practical exercises are suitable for their students with the resources and laboratory accommodation available, and what can be best done by demonstrations in class. It is hoped that the guidance given will enable the practical work to be undertaken successfully by any student who desires to obtain knowledge at first-hand—whether by teacher or by pupil.

Much of the Physics and Chemistry portions of the volume is from Gregory and Hodges' *Experimental Science for Indian Schools* and was prepared for this course of General Science by Mr. F. W. Hodges before his lamented death in 1938. Our friend, Mr. A. J. V. Gale, very kindly undertook to continue and complete what Mr. Hodges had done in selecting and revising suitable material from that volume; and we gratefully acknowledge the assistance he has thus given in the production of the present book. The biological Part of the book is entirely new.

R. A. GREGORY
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PART I

PHYSICS

CHAPTER I

GENERAL PROPERTIES OF LIQUIDS

THE term **matter** includes everything which occupies space and has weight; everything, in fact, of which we can become aware by our senses of feeling, smell, sight or taste and which can be weighed.

Matter may exist in the liquid state, in the solid state, or as gas, and the same matter may be found in all three states, depending on the conditions, as, for example, water, ice and steam.

Some special properties of liquids and solids will first be mentioned. A liquid adapts itself to the shape of the vessel containing it; but, the conditions remaining the same, it keeps its own size or *volume,* however much its shape may vary. A liquid has the power of flowing, but when at rest its free surface is always horizontal. Solid bodies differ from liquids in the fact that they keep their original *volume* and *shape* unless they are subjected to considerable force. They have the properties of rigidity or stiffness, and hardness. Their particles are so closely packed together, and have such a great attraction for one another, that the solids can sometimes be drawn out into wires or hammered into various shapes.

Pressure in a liquid depends upon depth.—If a small coin lies on the bottom of a glass of water or other liquid, there is a column of liquid resting on the coin. Suppose that the glass is at first half-full. Then if the glass is filled up, the column of liquid resting on the coin will be twice as high. Thus the pressure on the coin, due

to the weight of water resting on it, is doubled when the depth of water is doubled (Fig. 1). Pressure at any point in a liquid therefore depends on the *depth* of that point below the surface.

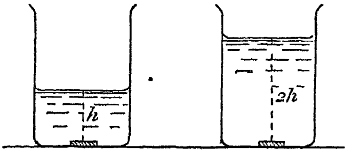


FIG. 1.—Pressure on a coin at a depth h in a liquid is doubled when the depth of liquid is made $2h$.

Upward pressure in a liquid.—A liquid contained in a stationary vessel remains at rest. Hence the downward pressure exerted by a column of liquid at any point below the surface must be balanced by an upward pressure at that point, otherwise there would be a continuous downward motion. That the pressure acting vertically upwards at a point in a liquid is equal to the downward pressure of the liquid above the point is true is easily demonstrated by the apparatus shown in Fig. 2.

A wide glass tube or cylinder, one end of which is covered with a disc of leather or cardboard to which a string is attached, is lowered into a liquid. It is found that water may be poured into the cylinder, without disturbing the disc, until the level of the water inside the cylinder reaches the same height as that outside; but, if more water be added, the downward pressure on the upper surface of the disc now exceeds the upward pressure of the outside liquid on the lower surface of the disc, which is therefore forced downward. So long as the level of the water inside the cylinder is below that of the water outside, the upward pressure on the disc from outside exceeds the downward pressure from inside, and the disc is held firmly against the end of the cylinder. When the water level is the same inside and outside, the disc is acted upon by equal upward and downward pressures.

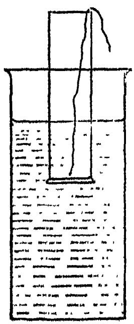


FIG. 2.—Disc is held in position by upward pressure until levels inside and outside tube are equal.

Buoyancy.—It is common knowledge that, on stepping into water a few feet deep, there is a curious sense of lightness or loss of weight; the water buoys one up, so that the body tends to rise up

through the water. With things which float, such as a wooden rod or a lead pencil, the results of this buoyancy which the water exerts can be seen by pushing the rod or pencil into the water and then letting go, when the solid floats up through the water to the surface. Even in the case of bodies which sink, there is the same buoyancy on the part of the water, but it is not enough to float them. The effect which the water has upon such bodies can, however, be seen in their loss of weight if they are weighed by a balance when hanging in water (Fig. 3).

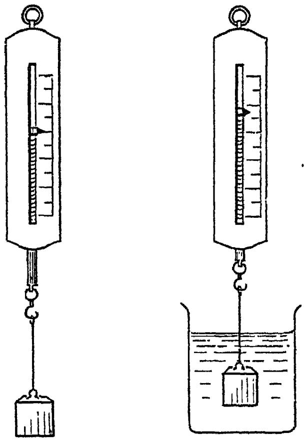


FIG. 3.—A cube of aluminium weighs in air 40 gm.; in water, the same cube weighs 25 gm.

Apparent weight of a solid in a liquid.—If a centimetre* cube of lead, or any other heavy material, be hung from a balance and then suspended in water, it will be found to weigh one gram less in water than it did in air. If two centimetre cubes of lead are suspended from the balance, the loss of weight is two grams. In every case the loss of weight measured in grams is equal to the number of cubic centimetres of the solid immersed in the water and, since 1 cubic centimetre of water weighs 1 gram, the loss is equal to the weight of the water displaced. This fact is known after its discoverer as the *Principle of Archimedes*.

The Principle of Archimedes.—**When a body is immersed in water it loses weight equal to the weight of the water displaced by it.** If the body be immersed in any other liquid, the loss of weight is still equal to the weight of an equal volume of that liquid. In other words, the upthrust experienced by an object immersed in a liquid is equal to the weight of the liquid displaced. It does not matter

* In scientific work, the units of measurement generally used are those of the Metric System, such, for example, as *centimetre* and *gram*. A table of equivalents in British units will be found on pp. 8-9.

of what substance a thing is made provided it does not dissolve in the liquid; the amount of loss of weight depends upon the *volume* of the part immersed and not upon the material.

Now it can be understood why some solids float and some sink. When an object weighs more than an equal volume of water, it sinks. When an object weighs less than an equal volume of water, it floats. When an object weighs the same as an equal volume of water, it neither sinks nor floats.

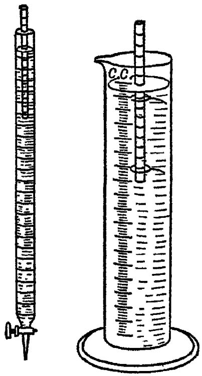


FIG. 4.—The number of cubic centimetres in the part of the rod under water is equal to the number of cubic centimetres of the water displaced.

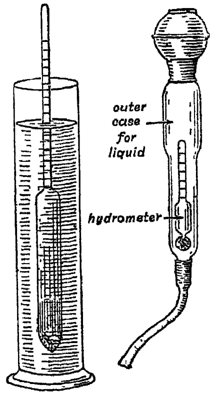
Water displaced by solids which float.—It is clear that a solid which sinks in water or in any other liquid displaces a volume of liquid equal to its own volume. When a solid floats, the case is slightly different. Part of the solid is in water and part out of the water, and, of course, only the part immersed is pushing the water aside in order to make room for itself. **In the case of a floating object, therefore, the volume of liquid displaced is equal to the volume of the part of the solid below the surface** (Fig. 4).

Proportion immersed when an object floats in water.—When any object is floating in water, a certain volume of it is under water and a certain volume is above the surface. The depth at which it floats depends upon its "heaviness". A block of heavy wood sinks deeper in water than a block of light wood of the same size. The water displaced by the heavy wood has therefore a greater volume, and consequently a greater weight, than that displaced by the light wood. But there is one important fact which applies to both cases. It is that **the weight of the water displaced by the immersed part of a floating object is equal to the whole weight of the object.** Hence, when a light object is placed in water, it sinks until it has displaced an amount of water which weighs the same as the whole of the floating object.

Since the depth at which an object floats in water is determined

by this rule, it gives a ready way of deciding whether an object will sink further in another liquid or not so far. If the liquid into which it is put is less dense than water, like methylated spirit, it is clear that to make up a given weight more of the liquid must be displaced. Consequently, to make up a weight equal to the weight of the floating body, the object will have to sink farther into the spirit than into the water. If, on the other hand, the object is placed in a liquid such as mercury, which is denser than water, it will not sink so far, because it will not take so much of this denser liquid to have a weight equal to that of the floating body.

The hydrometer.—This principle is utilised in an instrument called a hydrometer, by means of which the relative heaviness or denseness of a liquid can be compared with that of water. A common form of hydrometer is shown in Fig. 5. It consists of a sealed glass tube containing sufficient mercury to make it float vertically in water, and the stem is graduated so that the point to which it sinks in a liquid can be noted. The graduations are so arranged that the number marked on the stem at this point is the relative density of the liquid.



(i). (ii).

Fig. 5.—(i) A hydrometer floating in a liquid. The relative density is shown by the graduation mark at the surface of the liquid.

(ii) Hydrometer for determining relative density of accumulator acid. Acid from the cell is drawn into the wide tube, and the hydrometer within shows its relative density.

Ships and airships.—An iron ship floats in water although iron is relatively heavier than water. Owing to the air contained in the ship the weight of the whole is less than that of the same volume of water. Similarly, the fabric and equipment of a balloon or airship are heavier than air, but the balloon, or balloons within an airship, when filled with hydrogen gas, which is much lighter than

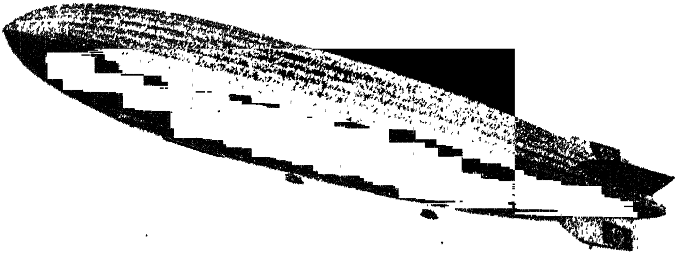


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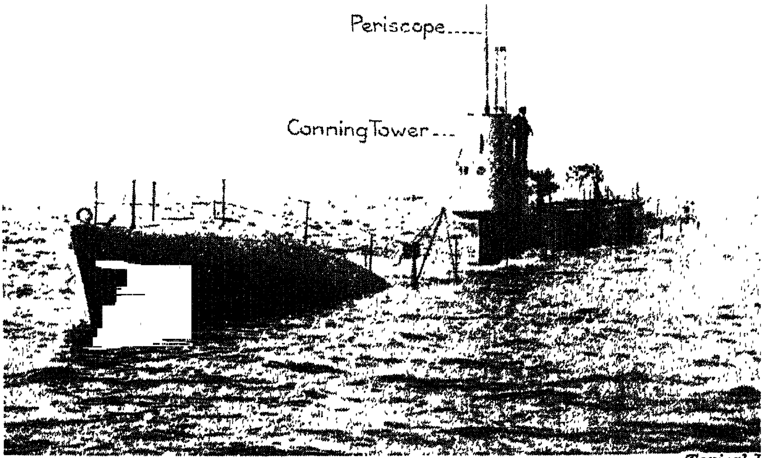
FIG. 6.—A modern airship. The rigid outer framework is covered with fabric. Many small bags filled with hydrogen or helium are contained inside the outer envelope. Engines driving propellers are fixed outside the envelope.

air, have less weight than the air displaced, and the balloon or airship therefore floats. Helium gas is used for airships in the United States, where it is abundant in natural gas coming from certain oil-wells, because, though it is heavier, bulk for bulk, than hydrogen, it is still much lighter than air, and, what is more important, it is non-inflammable.

Submarines.—A submarine (Fig. 7), when travelling on the surface of the water, has the greater part of its bulk immersed. The weight of the vessel and contents is then slightly less than that of the water it would displace if totally immersed. By admitting water to internal tanks, its weight can be increased so as to leave only the periscope exposed, and the weight of water displaced is equal to the weight of the vessel and its crew. By allowing more water to enter, its weight can be so much increased that the vessel sinks completely. By means of pumps, the water so admitted may be again expelled; the weight is then lowered, and the vessel rises. Diving may also



Topical I

Fig. 7.—A submarine coming to the surface. The conning tower is occupied by the commander of the vessel ; the periscope is a tube with an arrangement of mirrors which, when the vessel is submerged, can be made to project above the surface and enables those in charge to see their surroundings.

be accomplished by means of horizontal rudders when the boa in motion.

Icebergs.—When water freezes, the volume of ice formed greater than that of water (see p. 47). Hence a given volume of

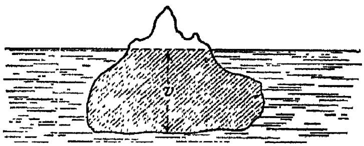


Fig. 8.—An iceberg. Only a small portion of an iceberg is visible above the surface of the sea.

is lighter than the same volume of water, and so floats on wa An iceberg floats with only about $\frac{1}{9}$ of its bulk above water. fresh water, which is relatively lighter than sea water, about $\frac{1}{12}$

its bulk would be above water. When ships are passing near icebergs great care has to be taken on account of the extent of ice hidde under water.

The aeroplane.—The aeroplane differs from the airship or balloo in being actually heavier than the medium in which it is immerse and travels. When a feather or any light body falls, the air-resistance to its downward motion is very apparent, and the aeroplan makes use of this supporting force of the air by means of its wing and tail, but it would be impossible for it to stay in the air if it ha no propulsive power. A large aeroplane has to have a minimum velocity of about fifty miles an hour in order to be maintained i flight in the air. If this necessary speed be lost, the loss of contro which almost invariably follows is highly dangerous unless the heigh be sufficient for the aircraft to recover speed. The principle of th aeroplane was understood long before it came into use, and it wa not until the invention of the light and powerful petrol engine tha flying in heavier-than-air machines became possible.

Equivalents of Metric Weights and Measures in terms of Imperia Units

Metric to Imperial

Linear Measure :	
1 centimetre ($\frac{1}{100}$ metre) - -	= 0·39 inch.
1 metre (m.) - - - - - -	= 39·37 inches. 3·28 feet. 1·09 yards.
1 kilometre (1000 m.) - -	= 0·62 mile.
Square Measure :	
1 square centimetre - - -	= 0·155 square inch.
Cubic Measure :	
1 cubic centimetre - - -	= 0·061 cubic inch.
Capacity Measure :	
1 litre - - - - - - -	= 1·76 pints.
Mass :	
1 gram (1 gm.) - - - -	= 15·432 grams.
1 kilogram (1000 gm.) - - -	= 2·20 lb.

Equivalents of Imperial Weights and Measures in terms of Metric Units

Imperial to Metric

Linear Measure :

1 inch - - - - -	= 2·54 centimetres.

Square Measure :

1 square inch - - - -	= 6·45 sq. centimetres.

Cubic Measure :

1 cubic inch - - - -	= 16·387 cub. centimetres.

Measures of Capacity :

1 pint - - - - -	= 0·568 litre.
1 gallon (4 quarts) - - - -	= 4·546 litres.

PRACTICAL WORK

1. **Upward pressure of water.**—(*a*) Procure a piece of wide glass tubing, or a straight lamp glass, having one end flat. If stiff leather is available, cut out a disc of slightly larger diameter than that of the glass, and pass a knotted thread through its centre. If a leathern disc cannot be obtained, make a disc of wood or stiff cardboard. Hold the disc tightly upon the flat end of the glass by means of the thread, and while doing so, lower the glass into a jar of water (Fig. 2). When the end of the glass with the disc upon it is a few inches below the surface of the water, the thread can be released and the disc will be found to remain in its position.

(*b*) Pour water very carefully into the inside of the glass, and notice the height inside and out at that moment when sufficient has been introduced to make the disc drop.

2. **Principle of Archimedes.**—(*a*) Hang a metal cube or cylinder from a spring balance, and write down its weight. Bring a beaker of water up under the metal and raise the beaker until the metal is completely covered by the water (Fig. 3). The pointer on the spring balance rises, showing that the metal has experienced an upthrust. Write down its apparent weight and, by subtraction from its real weight, find the apparent loss of weight.

Find, by measurement, the volume of the metal. Note that the number giving this volume in cubic centimetres is the same as that giving the loss of weight in grams.

Now the volume of water displaced by the metal is equal to the volume of the metal and, since 1 cubic centimetre of water weighs 1 gram, the weight of water displaced is equal to the loss of weight of the metal.

3. **Sinking and floating.**—Place several cubes of the same size of such substances as lead, iron, oak and cork, one after another, into a bowl of water. Observe that (1) some sink and others float; (2) of those which float, some are more immersed in the water than others.

4. **Flotation.**—Put some water in a *burette* or a jar graduated into cubic centimetres, and notice its level. Obtain a rectangular rod of wood 1 sq. cm. in section and about 15 cm. long. Weigh the rod and then place it in the jar. A loose loop of wire will keep the rod upright (Fig. 4). Notice how many cubic centimetres of the rod are immersed, and also how many cubic centimetres of water are displaced. Since the weight of 1 c.c. of water is 1 gram, the number of cubic centimetres of water displaced is also the weight in grams of the water displaced. This weight will be found equal to the weight of the whole rod.

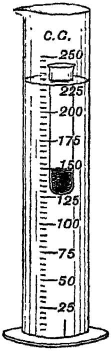


FIG. 9.—The weight of the test-tube and contents is equal to the weight of water displaced.

5. **Hydrometers.**—Fill the graduated jar with water up to a certain mark. Notice the level of the water.

Make a mark across a test-tube. Float the test-tube in the water and put sand into it until the mark upon it is on a level with the surface of the water. Notice the number of cubic centimetres of water displaced when the test-tube is thus immersed (Fig. 9).

Then take out the test-tube, dry it, and weigh it together with the sand it contains. The total weight of the test-tube and contents will be found equal to the weight shown by the number of cubic centimetres of water displaced. Repeat the experiment with the test-tube immersed to a different mark.

6. Place the loaded test-tube used in the preceding experiment (1) in milk, (2) in water, (3) in a mixture of milk and water, (4) in methylated spirits or turpentine. Observe the depth to which it sinks in each case.

CHAPTER II

FURTHER PROPERTIES OF LIQUIDS. DENSITY

Liquids in communicating vessels.—If several vessels of varied shapes (Fig. 10) are in communication with one another, and water be poured into any one of them, it is found as soon as the water has come to rest it will stand at the same level in all the tubes, however different the form of the vessels may be.

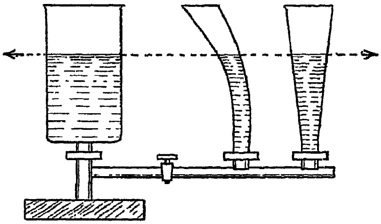


FIG. 10.—Liquids find their own level.

This property of liquids is used in the construction of the **water-level** (Fig. 11), an instrument used by surveyors and others

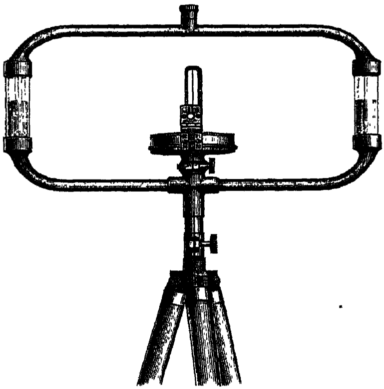


FIG. 11.—A simple water-level, mounted on a tripod, and with a compass at its centre.

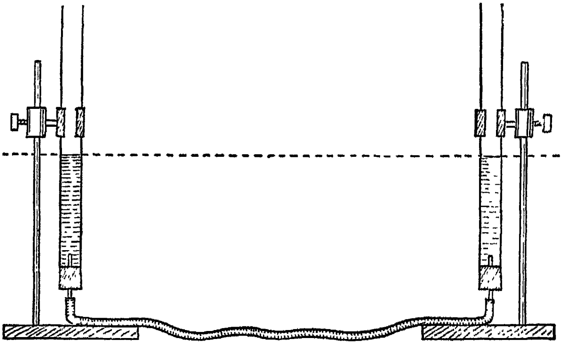


FIG. 12.—Arrangement to show principle of the water-level.

who require in their work to determine a horizontal line. The principle of the instrument can be shown by connecting two short, wide, upright glass tubes by a long length of rubber tubing (Fig. 12). However the arrangement of tubes may be standing, and however uneven the rubber tube may be, the line joining the two surfaces will always be level.

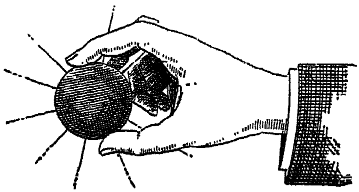


FIG. 13.—When a rubber ball pierced by small holes is filled with water, and squeezed, water squirts out with equal force in all directions.

Liquids communicate pressure equally in all directions.—If a rubber ball is pierced with small holes and is filled with water, it is seen that, on squeezing the ball, water is forced out equally at each opening—that is, pressure is communicated equally in all directions (Fig. 13).

Fountains.—If one of the glass tubes in the water-level model (Fig. 12) is unclamped and lowered, then the level of the water in that side, which it has been seen remains at the same height as that in the fixed tube, will come nearer the open end of the tube. Eventually, when the tube is lowered farther, it will overflow and, if the level in the fixed tube be kept at the same height by the addition of water, a jet of water will be forced up from the lowered tube to

about the height of the water-level in the fixed tube. Fixing a narrow nozzle to the tube will produce a thin jet of water such as is produced by a fountain. Clearly if the fixed tube be replaced by a large tank of water, and the single nozzle by a cap pierced by several fine holes, a fountain such as those in public parks can be made.

In a fountain, the water-supply is sometimes contained in a large tank on a tower, but more often the fountain is connected with the water-mains, where the water is under sufficient pressure to force the streams from the jets to a considerable height. Such fountains continue to "play" so long as the supply of water is available.

Water-supply of cities.—A city's water-supply may be drawn from mountain lakes situated at a high level. Water always flows from a higher to a lower level (p. 11), so that this ensures that the water will be delivered under considerable pressure. In the absence of this source of supply, water may be obtained from artesian wells or a river as shown in Fig. 14. In either case it must first be

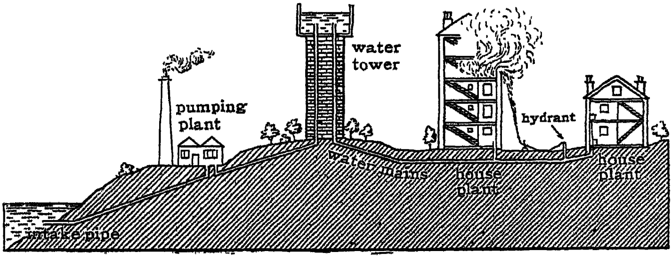


FIG. 14.—Town water-supply. The pump raises water from a river, and forces it up into tanks on a tower. By gravitation the water flows along pipes from the water tower to the town supply mains.

pumped up into reservoirs, situated at the highest point available, or, in flat neighbourhoods, into water-towers, so as to obtain the necessary pressure. From the tower, water is distributed by means of pipes known as mains, from which household supplies are drawn by smaller pipes. Pipes are also provided to give supplies in the streets (hydrants) for street washing, attacking fires, and similar public objects.

Meaning of density.—Different solids, though of the same size or volume, may differ in heaviness—that is, in weight. If the weights of 1 cubic centimetre of oak, lead, cork or brass are determined, one after the other, the lead will be found to be heaviest, the brass will come next, and then will follow the oak and cork in order. Thus equal volumes of these different solids have different weights. The weights will be found to be roughly as follows :

Substance	Weight of 1 cubic cm. in grams	Weight of 1 cubic foot in lb.
Lead	11·4	700
Brass	8·5	520
Oak	0·75	46
Cork	0·24	15

By filling two bottles of the same size with different liquids, it can also be shown that equal volumes of different liquids have different weights.

It is usual to speak of these facts by saying that things have different **densities.** Using the metric measures, it has been found by experiment that 1 c.c. of water weighs 1 gram at 4° C. The density of water is therefore said to be 1 gram per c.c. Again, 1 c.c. of lead weighs 11·4 grams and 1 c.c. of oak weighs 0·75 gram. The densities of lead and oak are therefore 11·4 and 0·75 grams per c.c. respectively.

Definition of density.—It is easy to compare densities when lumps of exactly the same size are used. Since the volumes are the same, it is quite clear that the thing with the greatest weight is the densest, and that which has the smallest weight is the least dense, so that the densities of these things can be compared by their weights. **Density is defined as the weight of unit volume of a substance.** Thus the density of iron is 7·8 grams per cubic centimetre, or 480 lb. per cubic foot ; the density of water is 1 gram per cubic centimetre, or 62·5 lb. per cubic foot ; the density of turpentine is 0·87 gram per cubic centimetre, or 54·2 lb. per cubic foot. In all cases where the density of a substance is referred to, the units used must be stated to give the numbers a meaning. It follows from the above definition that when the volume of a body is multiplied by its density, its weight is obtained.

$$\text{Volume} \times \text{density} = \text{weight},$$

$$\text{or density} = \frac{\text{weight}}{\text{volume}}.$$

In using this relation between the volume and weight, the proper units must be employed. In all scientific work, the cubic centimetre and gram are adopted as the units of volume and weight respectively.

Relative density.—**Relative density**, often called **specific gravity**, is the mass or weight of a substance compared with that of an equal volume of another substance taken as a standard. For solids and liquids the standard substance is water. Since the weight of 1 c.c. of water is 1 gram, the weight of an equal volume of water in grams is always equal to the volume of the substance in c.c., so that if the metric system is used the numbers representing density and relative density are the same; this is not the case when the British units are employed.

Relative densities of liquids.—A simple method of determining the specific gravities, or relative densities, of substances is to use a **specific gravity**, or **relative density, bottle.** Such a bottle often consists of a small glass stoppered flask, holding about fifty grams of water. The bottle is counterpoised upon a balance, or weighed, and is then filled in succession with water and the liquid of which the specific gravity has to be determined. By dividing the weight of the liquid by the weight of the equal volume of water, the specific gravity is found.

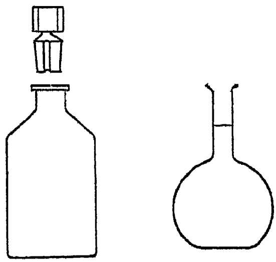


FIG. 15.—Specific gravity bottles.

Instead of a bottle of this kind, a flask having a narrow neck, around which a horizontal mark has been made, may be used. The weight of water which fills the flask up to the mark may thus be compared with the weight of liquid which fills it to the same mark.

Suppose the weight of water in a relative density bottle was found to be 50 grams, and the weight of the same volume of methylated spirit was found to be 40 grams. Then these numbers show the relative

densities of the two liquids, and as the density of water is taken as the standard, the relative density of the spirit is equal to 40 divided by 50. It is thus seen that the relative density of spirit is represented by the fraction $\frac{40}{50}$ or $\frac{4}{5}$, which, expressed as a decimal fraction, is 0·8.

The density of many liquids is greater than that of water. Thus, milk has a relative density represented by the number 1·03, or $1\frac{3}{100}$, so that equal volumes of water and milk would have weights in the ratio of 100 to 103.

Use of a hydrometer.—A quick method of finding the relative density of a liquid is to use a hydrometer (p. 5). The stem of the instrument is graduated by the manufacturer so that the reading on the stem at the surface of a liquid in which the hydrometer is floating gives the relative density or specific gravity. Thus, in water the reading is 1, in spirit 0·8, and so on. Different forms of hydrometers are used to test the specific gravity of milk to guard against addition of water, to test beer and spirits, and to find the specific gravity of the acid in an accumulator, which is 1·24 when the accumulator is charged and decreases gradually as it is used.

Relative densities of solids.—A relative density bottle can be used to find the relative densities of small solids as well as of liquids. The solid is first weighed and then placed in one pan of a balance by the side of a relative density bottle filled with water. The solid with the bottle is counterpoised by placing weights in the other pan. After removing the bottle from the balance, the solid is placed in it. A certain amount of water overflows and is removed. When the bottle is put back on the balance, weights have to be removed from the pan to make up for the water removed. The total weights, in grams, thus removed represent the weight displaced by the solid, and therefore the volume of the solid in cubic centimetres. By dividing the weight of the solid by the weight of water displaced by it, the relative density can be found. Only solids insoluble in water can, of course, be used.

Relative densities determined by Archimedes' Principle.—When a body is immersed in water, it appears to lose weight by an amount

equal to the weight of water displaced. Subtracting the weight of the body in water from its weight in air gives the weight of the volume of water equal to the volume of the solid; hence by dividing the weight in air by the weight of water displaced, the specific gravity of the solid is obtained.

This method can also be used for solids such as cork which float on water. The cork is first weighed. Then a piece of lead or a weight sufficient to make the cork sink is hung from the balance arm, immersed in the water in the beaker standing on platform *H* (Fig. 16), and counterpoised. The cork is then attached to the sinker, so that it and the sinker are completely immersed and the loss of weight found. Since the sinker was immersed during both weighings, the loss of weight represents the weight of water displaced by the cork. Then, as before, weight in air divided by apparent loss of weight in water gives the relative density.

PRACTICAL WORK

1. Weight of unit volume.—(*a*) Obtain a number of inch cubes or centimetre cubes of different substances, such as wood, cork, iron and lead. Cut other cubes of the same size out of soap, plasticine, clay, and similar materials. Lift the cubes one after the other. Notice that though they are of the same size or volume, they differ in heaviness.

Weigh the cubes in succession, either with a spring balance or a pair of scales, and record the weight of each.

(*b*) Find, by measurement, the number of cubic centimetres or cubic inches in a wooden block. Weigh the block. From the two results calculate the weight of one cubic centimetre or cubic inch.

2. Weight of equal volumes.—Counterpoise a bottle in a pair of scales. Transfer to the bottle from a measuring-glass a certain number of cubic centimetres of water, so as nearly to fill the bottle. Find the weight of the water thus added, and then calculate the weight of one cubic centimetre of water. In a similar way find the weight of a cubic centimetre of one or two other liquids, such as kerosene and salt solution.

3. Weight of 1 c.c.—Obtain cubes or cylinders of wood, iron and glass and find their volumes by measurement. Weigh each solid measured, and determine the weight of 1 c.c. of the substance.

4. Density of a pebble.—Find the weight of a stone pebble and also its volume (by sliding the pebble into a measuring-cylinder containing

a known volume of water and observing the increase in volume due t the pebble). Thence determine the weight of one cubic centimetre (the pebble—that is, the density of the stone.

5. **Problem.**—Determine the area and density of a rectangular piec of metal foil. Use your results to find the thickness of the foil.

6. **Relative density or specific gravity, using Archimedes' Principle.**– (*a*) Find, by displacement of water, the volume of a glass stoppe Write down the weight of an equal volume of water. Weigh the stopp(

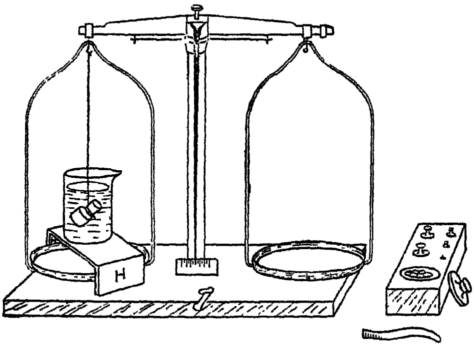


FIG. 16.—How to find the weight of an object suspended in water, using a chemical balance.

in air and in water. Note the loss of weight in water. Compare th with the weight of water displaced.

(*b*) From the data of the last experiment, find the specific gravity (the glass stopper.

$$\text{Specific gravity of stopper} = \frac{\text{weight in air}}{\text{loss of weight in water}}.$$

7. **Specific gravity bottle.**—(*a*) Counterpoise a specific gravity bottl upon a balance. Fill the bottle with water, and weigh it ; then empt the bottle, dry it, and fill it with turpentine. Now weigh the bottl again with the turpentine in it.

$$\text{Relative density or specific gravity} = \frac{\text{weight of substance}}{\text{wt. of eq. vol. of water}}.$$

(*b*) Following the method of the previous experiment, determine th relative densities of two or three liquids.

8. **Specific gravity determination.**—Weigh out about 100 grams (small nails. Fill the specific gravity flask with water, and counterpoi it together with the nails. Next put the nails into the bottle, an

remove the water displaced. Take off weights until the index of the balance swings evenly. The weights taken away must equal the weight of the water displaced—that is, the weight of a volume of water equal in volume to the nails. Therefore

$$\text{Specific gravity of the nails} = \frac{\text{weight of nails}}{\text{weight of water displaced}}.$$

The volume of 1 gram of water being 1 c.c., the volume of the nails can be found.

CHAPTER III

PROPERTIES OF GASES. THE ATMOSPHERE

Characters of gases.—The leading difference between a solid an a liquid is the power of flowing which the latter possesses. Gas also possess fluidity, and to a much more marked degree tha liquids. But whereas liquids are almost incompressible, gases a easily compressed into a smaller space.

A liquid always adapts itself to the shape of the containing vesse and presents a level surface ; a gas, on the other hand, will, howeve small its volume, spread out and fill any vessel containing it, hov ever large ; and it does not present any definite surface to th surrounding air. Another distinction will be more fully appreciate after the action of heat upon the volume of bodies has been co sidered. Generally speaking, all bodies become larger as they a heated ; this is much more decidedly the case with gases than wit liquids. **Gases, then, are easily compressible and expand indefinitely.** Th being so, gases always tend to withstand any pressure exerted o them and, if possible, to overcome that pressure, and to expand b means of the pressure which they themselves exert.

Air exerts pressure.—Everything which has weight can exe pressure. The pressure depends first of all upon the density c weight of unit volume of a thing. For example, if a piece of iro is carried upon the shoulder it exerts more pressure than a piece c wood of the same size. But the pressure also depends upon th amount of material carried. Thus, a sack of wool would exert mo pressure than an iron nail. It will be understood, then, that thoug the air is so light compared with other substances, a large quantit of it would be very heavy and would exert a very great pressure.

The air extends upwards from the surface of the earth for man miles ; and owing to this, it presses very heavily upon everything.

The reason why a leathern or rubber sucker is difficult to pull off an object upon which it has been placed is that the air is pressing upon the outside of the sucker but not upon the inside. Suckers to which hooks are attached are sometimes used to support light objects displayed on glass windows in shops (Fig. 17), while certain organisms, such as the octopus, attach themselves to an object by means of suckers.

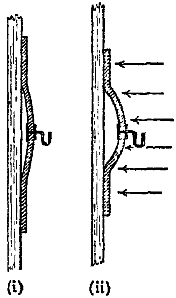


FIG. 17.—A rubber sucker carrying a hook is pressed on to a glass window (i). Light objects can be hung from the hook, pressure of the air on the sucker keeping it attached firmly to the glass (ii).

Air presses in all directions.—The pressure of air is not only downwards, but also upwards and sideways ; in fact, in all directions. If the pressure were only exerted downwards, then a sucker could be pulled off an object on which it is fixed by turning the object upside down, or sideways. But the sucker cannot be pulled off any more easily whichever way it is turned.

The upward pressure of the air can be shown by filling a tumbler full of water and, after placing a flat piece of cardboard over the top, turning the tumbler upside down, as shown in Fig 18. If the experiment is done carefully, the water will remain in the tumbler, because the downward pressure of the water is unable to overcome the upward pressure of the air on the cardboard.

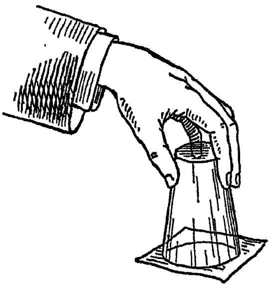


FIG. 18.—The paper does not fall off though the glass is full of water.

When a liquid is drunk from a glass by means of a straw or tube, it is really the pressure of the air which forces the liquid up the tube. This can be shown by fitting the tube into a cork in the neck of a bottle containing water or any other drinkable liquid. The liquid cannot be sucked out of the bottle whilst its surface is not open to the air, but by loosening the cork,

air is admitted, and the liquid can then be obtained by suctior Casks and similar vessels containing liquid are provided with vent plug to admit air, so that the liqui can be drawn off when the plug is pulle out and the tap is turned on. Unless the plu is out, the liquid will not flow from the tap.

Gases and liquids exert pressure in a directions, thus differing from solids, whic exert pressure in one direction only, namely downwards.

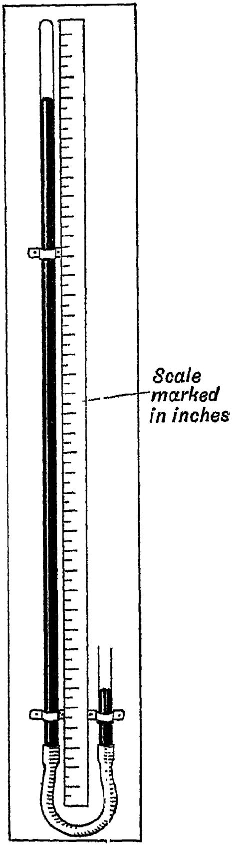


FIG. 19.—Simple barometer. Difference in height of the mercury in the two limbs gives the pressure of the atmosphere in inches or millimetres of mercury.

Why the weight of the air is not felt.—Though the whole weight of the air is pressin upon the body, we do not feel it. The lungs which fill up a large part of the chest space are filled with air, and this air is in free com munication with the atmosphere through th throat and mouth. The result is that th air in the lungs presses them outwards fror the inside just as much as the atmospher presses them inwards from the outside, an so no inconvenience is felt. Similiarly, a soa bubble is not crushed by the pressure of th air, because the pressure is the same insid and outside its surface.

How the pressure of the air is measured.—It is important to have a means of measurin how much the air presses upon things on th earth's surface. The instrument shown i Fig. 19 enables this to be done. The to of the long tube is sealed so that the ai cannot press upon the mercury in it, bu the small tube is open and the air can there fore press upon the surface of the mercur there.

The column of mercury is supported b some means which is not at first evident. I

this were not so, the mercury would sink to the same level in the long and the short tubes, as they are in free communication. If a hole were made in the closed end of the tube this would immediately happen. The column of mercury, which is about thirty inches high, is therefore kept in its position by the downward pressure of the atmosphere upon the surface of the mercury in the short open tube.

For an instrument of this kind to show the pressure of the atmosphere accurately, great care has to be taken that no air enters the space at the top of the long tube. If air does enter, it will press upon the surface of the mercury in the long tube, and the height of the mercury will be less than thirty inches. In such a case, instead of measuring the whole pressure of the atmosphere, what would really be measured would be the difference between the pressure of the whole atmosphere and that of the air enclosed in the longer tube. In a properly constructed instrument, therefore, there is nothing above the mercury in the longer tube except a little mercury vapour. An arrangement like that described constitutes a barometer. **A barometer is an instrument for measuring the pressure exerted by the atmosphere.**

The height of the mercury column—that is, the vertical distance between the levels of the mercury in the two limbs—only varies slightly under ordinary conditions since the atmospheric pressure only undergoes small changes. The actual pressure is measured either in inches or millimetres of mercury by means of a scale reading from 28 in. to 32 in. as shown in Fig. 22, or from 700 to 800 mm. Barometer readings are now often quoted in **millibars**, this unit being approximately $\frac{1}{1000}$ of the standard atmospheric pressure, 750 mm.

Changes in pressure of the air.—If, for any cause, the pressure upon the surface of the mercury in the open tube increases, the mercury in the long tube will rise. If, however, the pressure becomes less, the mercury column in the long tube will get shorter. The effect of an increase of pressure can be shown by blowing into the short tube, when the mercury rises. With the approach of a violent storm, the pressure of the atmosphere generally decreases considerably, and the barometer or " glass ", as seamen term it, is said to " fall ".

Another form of mercury barometer.—Instead of using a baro meter of the U-tube form, a straight tube sealed at one end may b filled with mercury, and inverted in a small dish of mercury, a shown in Fig. 20.

A column of mercury will then be supported in the tube by th pressure of the atmosphere. The distance between the top of th column and the surface of the mercury in the dish will be abou 30 inches, or 76 cm., when the tube is vertical, or in the position

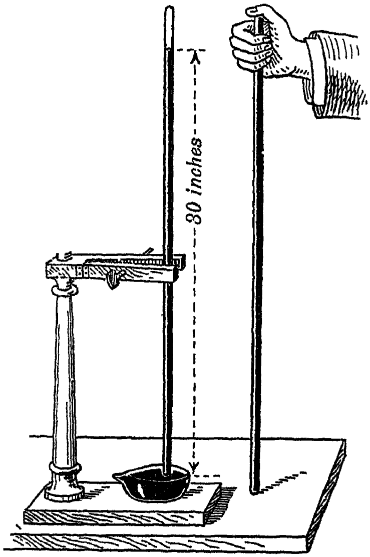


FIG. 20.—The tube is first filled with mercury, and then placed with the open end in a dish of mercury. A column of mercury about 30 inches high remains in the tube.

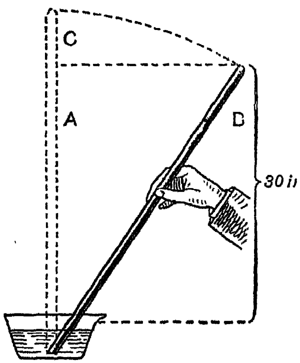


FIG. 21.—The tilted gla tube is full of mercury, but if is placed upright in the positio A, the mercury will not fill i and there will be nothing visib in the part C.

in Fig. 21. If the tube be inclined to the position B, so that th closed end of it is equal to or less than this height above the mercur in the dish, the mercury fills the tube completely, showing that th space C above the mercury, when the tube was in the position A, di

not contain air. It will be clear from this that if the tube were less than 30 inches long it would be entirely filled by the mercury. On an average, the atmosphere at the sea-level will balance a column of mercury 30 inches in vertical height. No matter if the closed tube is 30 feet long, the top of the mercury column will only be about 30 inches above the level of the mercury in the cistern. The empty space above the column of mercury in the tube is often called the **Torricellian vacuum,** after the Italian physicist, **Torricelli** (1608-1648), who first described the experiment.

Mercury is a convenient liquid for barometers.—Mercury is used in barometers for several reasons. Since the column of mercury which the atmosphere can support is 30 inches high, it is clear that if a lighter liquid be used, a longer column of it would be supported. For example, water is $13\frac{3}{5}$ (13·6) times lighter than mercury, therefore the column of water which could be supported would be $30 \times 13\frac{3}{5} = 408$ inches $= 34$ feet, which would be a very inconvenient height for a barometer. The length of a column of glycerin which can be supported by the pressure of the air is 26 feet.

Pressure of the atmosphere at different altitudes.—Because the atmosphere has weight, the longer the column of it there is above the barometer, the greater will be the weight of that column, and the more it will press upon the mercury in the barometer. Hence, on rising up through the atmosphere with a barometer, there is less air above it pressing upon it, and, in consequence, the column of mercury the air can support will be less. On descending from any position, for example down the shaft of a mine, the mercury column will be pushed higher and higher as the length of the column of air above it is increased. Since the height of the column of mercury varies thus with the position of the barometer, it is clear that the alteration in its readings supplies a ready means of finding the height of the place of observation above the sea-level.

It was **Blaise Pascal,** a brilliant French mathematician and physicist, who first suggested the experiment of carrying a barometer up a mountain and noting the effect upon the height of the mercury in the tube. The experiment was made in September, 1648, on the Puy de Dôme, Auvergne, and it was found that

the mercury fell from 26 inches to 23 inches in ascending the mountain.

At a height of $3\frac{1}{2}$ miles from the sea-level, the mercury column only stands 15 inches high instead of 30 inches, thus showing that by rising to that height half the atmosphere is left behind. This does not mean that the atmosphere is only 7 miles high, for really there is air, though very thin and rarefied and therefore of much lower density, at a height of 100 or 150 miles above the earth's surface. But the air below a height of $3\frac{1}{2}$ miles is so much denser than that above this height, on account of its being compressed by the air above it, that it produces the same effect as the much greater thickness of less dense air.

The following table shows how the barometric readings vary with the heights above sea-level at various places in India :

Height of station above sea-level in metres and feet			Mean pressure in millimetres and millibars	
Calcutta	6·4 m.	21 ft.	762·3 mm.	1016·6 mb.
Madras	6·7 m.	22 ft.	760·5 mm.	1015·8 mb.
Bombay	11·3 m.	37 ft.	759·2 mm.	1014·8 mb.
Allahabad	94·1 m.	308 ft.	754·9 mm.	1006·8 mb.
Peshawar	339 m.	1,112 ft.	734·7 mm.	979·9 mb.
Bangalore	929 m.	3,018 ft.	685·8 mm.	914·4 mb.
Simla	2,205 m.	7,234 ft.	586·6 mm.	782·2 mb.
Darjiling	2,266 m.	7,435 ft.	582·1 mm.	776·2 mb.
			(1 bar = 750 mm. at 45° Lat. and 0° C. sea-level.)	

The barometer and the weather.—The barometer measures the atmospheric pressure. This pressure, in any particular spot, depends upon the weight of air immediately overhead. The pressure of the air, in turn, depends upon atmospheric conditions. The air in motion follows generally circular paths, and at the centre of such a circle the pressure is generally low for one direction of rotation and high for the other, but fall in pressure generally means cooling of the air and condensation of moisture to form rain. Rise in pressure generally means warming and consequent dryness of

the atmosphere. The "rise" or "fall" of the barometer is therefore used to give warning of changes of weather.

A standard barometer.—For accurate measurements of pressure, a standard form of barometer is used, such as that illustrated in Fig. 22. The whole of the barometer with the exception of the upper and lower levels of the mercury is enclosed in a metal case. By means of a screw the level of mercury in the cup is raised or lowered to a fixed zero point before a reading is taken. On the upper part of the case is a scale the zero of which is at the fixed zero point. This scale is furnished with a vernier worked by a thumb-screw, by means of which the height of the mercury can be read very accurately. The eye is brought to the level of the top of the mercury column and the screw is turned until the top of the vernier coincides with the top of the mercury column. Mirrors are fitted behind the upper and lower surfaces of the mercury, to assist the taking of accurate readings.

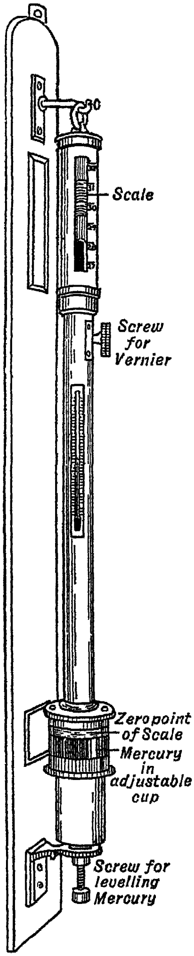


FIG. 22.—A Fortin or standard barometer.

A thermometer is also fitted to the instrument and a correction is applied for the alteration in density of the mercury for any particular temperature.

The aneroid barometer.—This barometer contains no mercury (Fig. 23). It consists of a circular box of metal which is almost exhausted of air. The sides of the box are flexible and are very sensitive to changes in pressure, being pressed inwards when the atmospheric pressure increases and moving outwards when it becomes less. This movement is communicated by a spring and a system of levers to an indicator which moves round

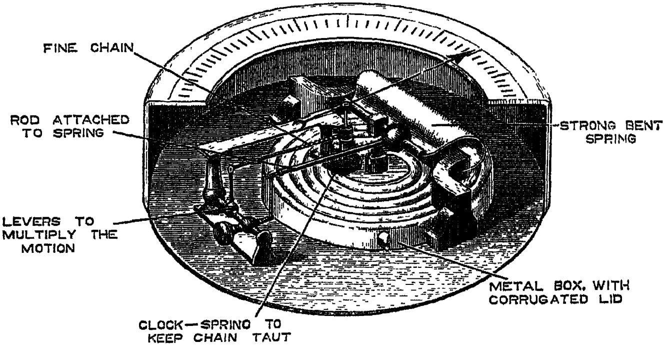


FIG. 23.—An aneroid barometer.

the clock-face of the instrument. Though a good mercury baromet is more accurate than an aneroid barometer, yet, on account its being much handier for transport, the aneroid is the type instrument commonly used by travellers and in ships and aircra

Air pressure and volume.—If air be enclosed in a cylinder fitt with a piston, it can be compressed—that is, its volume can decreased by pushing in the piston. The volume occupied by gas thus depends upon the pressure to which the gas is subjected.

Accurate measurements of the relation between the volume a the corresponding pressure of a gas can be made with the apparat represented in Fig. 24. Two glass tubes are connected with thi india-rubber tubing. The left-hand tube is sealed at the tc Mercury fills the rubber tubing and part of each glass tube. D air is enclosed in the left-hand tube. By sliding up or down t support to which the open tube on the right is fixed, the air enclos by the mercury may be put under different pressures. When t level of the mercury is the same in both tubes, the pressure of t enclosed air is the same as that of the atmosphere. By raising t open tube, the enclosed air can be put under pressures greater th that of the atmosphere, and by lowering it, the pressure can made less than that of the atmosphere. The scale on the apparat enables the volume of air in the closed tube above the mercu

to be measured. Also the difference of level of the surfaces of the mercury in the two tubes, added to or subtracted from the height of the barometer, gives the pressure to which the air is subjected.

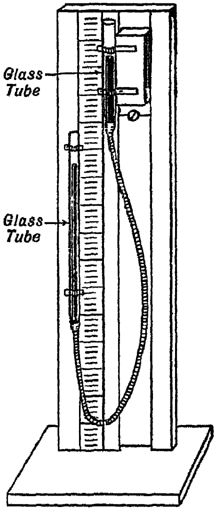


FIG. 24.—Apparatus for experiments on Boyle's Law.

When the results of experiments are tabulated, certain important relations between the volume of a gas and the pressure to which it is subjected become evident. It is found that the volume regularly diminishes as the pressure is increased, and in the same proportion. It is also found that as the volume of a gas increases, the pressure upon it diminishes, and exactly in the same proportion.

But in both these cases, it is assumed that the temperature of the gas remains the same—that is, the temperature of the gas under the different pressures must not alter.

The tabulated results of the experiments reveal another important relation, which is, however, another way of expressing those already noticed. It is found that, when there is no alteration of temperature, the product obtained by multiplying the volume of a given quantity of gas by the pressure to which it is subjected is always the same, or remains constant.

These facts were discovered by **Boyle**, and are included in what is known as **Boyle's Law**. It can be expressed by saying that **when the temperature remains the same, the volume of a given quantity of gas varies inversely as its pressure.** Or, what is the same thing, **the temperature remaining the same, the product of the pressure and the volume of a given quantity of gas is constant.**

Vapour pressure.—When a gas is enclosed in a gas-jar or other vessel standing over water, water vaporises into the gas, which becomes *saturated* with water vapour. This vapour exerts a pressure of its own, so that if P is the actual pressure of the gas, and p that of water vapour, then, when the level of water inside and outside

the gas-jar is the same (Fig. 25), $P+p=A$, the atmospheric p sure. Since pressure exerted *by* the gas is equal to pressure exei *on* the gas, the actual pressure on the ga $A-p$.

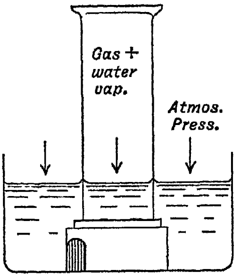


FIG. 25.—Gas standing over water in a gas-jar is saturated with water vapour which exerts a definite pressure.

Again, if a drop of water or other vola liquid is introduced into a barometer t so that it rises above the mercury, it once vaporises wholly or in part, exerts p sure, and lowers the mercury column, giv a false barometric height.

PRACTICAL WORK

1. **Observations on the pressure of air.**— Dip a pipette into water. Place your finger c the top and lift the tube out of the water. No that the water does not run out of the tube although the bottom is op

(*b*) Moisten a leathern sucker, press it upon a flat stone, and no that it can be pulled off only with difficulty, owing to the atmospl pressing upon its upper surface.

(*c*) Take a tumbler or cylinder with ground edges and completely it with water. Place a piece of card or stout writing paper across top and invert the vessel. If the air has been carefully kept from en ing the tumbler, the water does not run out.

2. **The principle of the barometer.**—Tie a short piece of thick india-rubber tubing upon the open end of a barometer tube. Tie the free end of the tubing to a glass tube about six inches long, open at both ends. Rest the barometer tube with its closed end downwards, and pour mercury into it (being careful to let all air bubbles come out) until the liquid reaches the short tube. Then fix the arrangement upright as in Fig. 19. A scale is marked on the supporting board, from which the difference in height of the mercury in the two tubes can be measured.

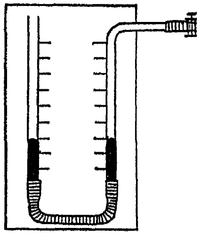


FIG. 26.—Appara for measuring press exerted by the lung

The air pressing upon the surface of the mercury in the short open arm of the U-tube balances the column of merc in the closed arm.

3. **The pressure exerted by the lungs.**—Fasten together by rub pressure tubing two long glass tubes (Fig. 26) : fix the tubes on a wooc

stand and mark a scale of inches at the side of each tube. Fit one of the tubes with a rubber tube, on which is a clip. Pour mercury into the other tube until, after unfastening the clip, it is well above the rubber connecting tube.

Now blow into the side tube steadily, exerting the full force of your lungs. With the tube still in your mouth, fasten the clip. Measure the difference in height of the two mercury columns. This, added to the atmospheric pressure, measures the pressure exerted by the lungs.

CHAPTER IV

SYRINGE, PUMPS AND SIPHON

Principle of the syringe.—A syringe consists of a tube, or barrel as it is termed, in which is a closely fitting piston with a handle projecting from one end of the barrel. The other end of the barrel is fitted with a nozzle (Fig. 27), or, in the case of a glass syringe, the end of the barrel is drawn out to form a nozzle. The syringe is

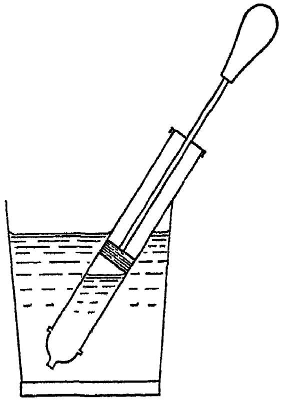


FIG. 27.—A garden syringe with piston partly raised.

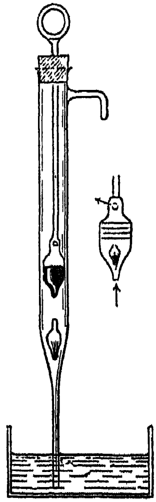


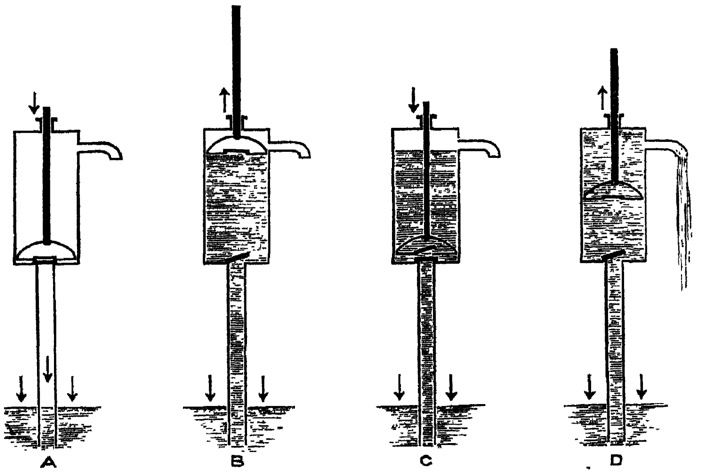
FIG. 28.—Glass model of a simple suction pump.

stood in water, and the piston is raised. This allows air inside the syringe to expand, and its pressure is reduced. The air pressure outside now forces water into the syringe. When the piston is pressed down, the inside pressure becomes greater than the air pressure outside, and the water the syringe contained is forced out.

The suction pump.—After examining a glass model like that shown in Fig. 28, the action of a suction pump can easily be

stood. To begin with, suppose that the pump is full of air
ıat the end of the tube below the valve is dipped into a basin
ter; the piston is at the bottom of its stroke (Fig. 29, *A*). As
ston is raised, the air in the cylinder expands, and its pressure
quently decreases; the pressure on the lower surface of the
at the bottom of the cylinder is, therefore, soon greater than
on its upper surface, and the valve is pushed upwards by the
low it, the air flowing into the cylinder. The result of this is
he air in the cylinder and tube below the piston is at a lower
ıre than that of the outside air, and as a consequence water is
d up the tube.

the piston descends again, the air in the cylinder below the
ı is compressed, and its pressure becomes gradually greater.
closes the valve at the bottom of the cylinder and opens that
e piston, through which, of course, the air in the cylinder
es. On raising the piston again, the same effects are repeated
all the air in the pump is removed and the outside air pushes
water up until it fills the barrel completely (Fig. 29, *B*).



'IG. 29.—Sections showing four stages in the working of a common pump.

G.B.S.

On pushing the piston down again, the piston valve opens and the cylinder valve shuts, water remaining in the cylinder to the level of the spout (Fig. 29, *C*). On raising the piston again, the piston valve is closed by the pressure of water above it, and the water in the cylinder is lifted out of the spout ; meanwhile, the reduction of pressure below the piston has caused the outside air to force more water up the pipe, lifting the cylinder valve and entering the cylinder (Fig. 29, *D*) in readiness for the next down stroke.

It has been shown that the air is able to support a column of mercury 30 inches in height, and as mercury is 13·6 times heavier than water, it is clear that the air could support a column of water of a height equal to 30 inches $\times$ 13·6 $=$ 408 in. $=$ 34 ft. Since the action of the common pump depends upon the height of the water column which can be balanced by the pressure of the atmosphere, its spout must never be more than 34 feet from the level of the water in the well. In practice, on account of leakage of air into the pump, it is rarely more than 25 feet from the water-level to the spout.

The bicycle pump.—This is a compression pump. It is made of metal or vulcanite. The head of the piston is fitted with a leather washer which is cup-shaped, as shown in Fig. 30. On pulling out the handle, air goes into the space between the piston and end of the pump, passing between the washer and the wall of the cylinder. On pushing in the handle, the air beyond the piston presses the edges of the washer tightly against the sides of the cylinder, so that no air passes back, and compression therefore takes place. This increased pressure is also sufficient to overcome the resistance of the valve connected to the air-tube of the bicycle tyre. The valve (Fig. 31) consists of a metal tube with a closed end but having a small hole in the side. This is covered by a piece of rubber tubing. When the air is sufficiently compressed by the pump, it forces its way between the rubber and the metal tube and so enters the tyre. The rubber tube prevents the air from passing back into the pump when the pump handle is again pulled out.

Pneumatic tyres.—The pneumatic tyre consists of an outer thick rubber casing and an inner thin-walled rubber container, which is gas-tight and can be blown up like a football bladder. A pump and

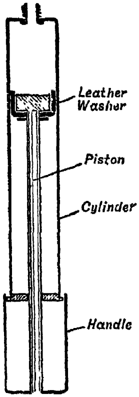


FIG. 30.—A bicycle pump.

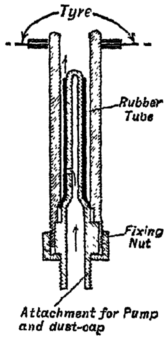


FIG. 31.—A bicycle valve. The compressed air from the pump follows the path shown by the arrows.

valve, such as those described on p. 34, are used for blowing up the tyre and so filling the inner tube with air. Pneumatic tyres use less rubber than solid rubber tyres, and absorb the shocks due to unevenness of a road surface much more effectively.

The air-pump.—The air-pump is used for removing as much air as possible from a container. Several forms are in use but only the simplest will be described—that designed by Hawksbee, the essential parts of which are shown in Fig. 32. The receiver, from which air is to be removed, is connected with a cylinder by means of a tube, shown on the base in Fig. 32, bent twice at right angles. Just at the bottom of the cylinder is a valve opening upwards. In the cylinder a piston works, in an air-tight manner, with a valve also opening upwards; and a handle for moving the piston up and down is provided.

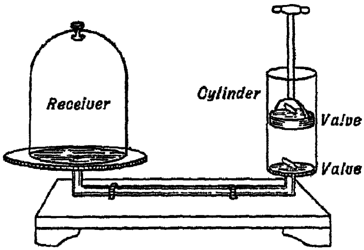


FIG. 32.—Simple form of air-pump.

The action is precisely the same as that of the suction pump described on p. 32; instead of water being forced into the cylinder by the pressure of the atmosphere, the pressure of air in the receiver causes the cylinder valve to open. When the piston is pushed down, the air between the valves is compressed, causing the lower valve to shut; but as the piston descends, the pressure on the under surface of the upper valve becomes greater than that of the atmosphere upon its upper surface, so that the valve opens upwards and the air in the space rushes through the open valve into the outside air. The final result, when the piston reaches the bottom of the cylinder, is that there is less air in the receiver and tube connected with it than there was originally. As the piston is worked up and down, the same opening and shutting of valves is repeated, with the result that most of the air is removed from the receiver, provided that the piston and valves fit tightly.

Vacuum fountain.—A pretty demonstration of the effect of atmospheric pressure is given by the vacuum fountain (Fig. 33). A round-bottomed flask is fitted with a rubber stopper, through which a short piece of glass tube is passed. The end of the tube within the flask is drawn out to a fine point, and the other end is fitted with a piece of thick rubber tubing provided with a clip. A little water is poured into the flask, which is heated carefully until plenty of steam rushes out of the open rubber tube. After a few minutes, the steam will have displaced most of the air from the flask. The flame is then removed and the clip on the rubber tubing screwed up as quickly as possible; the clip must on no account be screwed up while the flame is beneath the flask, for the pressure might cause an explosion.

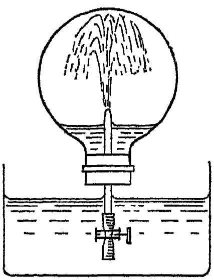


Fig. 33.—Vacuum fountain.

When the flask has cooled down, most of the steam it contained will have condensed, leaving practically a vacuum in the flask, apart from the presence of water vapour. If the flask be then stood upside down with the rubber tube dipping into water and the clip unscrewed, the pressure of the atmosphere will force water up the

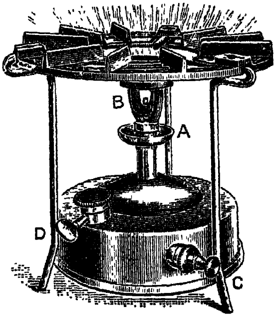


FIG. 34.—Primus stove.

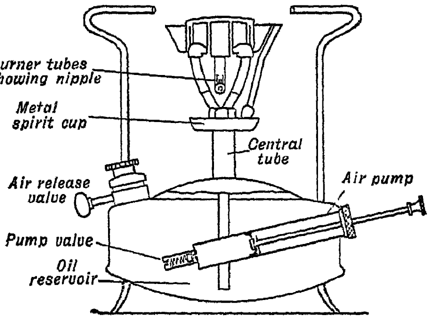


FIG. 35.—Primus stove (diagrammatic).

tube into the flask, where it will issue from the fine jet as a fountain, continuing until the flask is full of water. A round-bottomed flask is used for the experiment, because it is better able to withstand the pressure of the atmosphere when the vacuum is produced.

The Primus stove.—This stove (Fig. 34), often used for cooking purposes where gas is not available, works on the same principle as the Bunsen burner. The combustible substance is oil, but air is admitted to the flame, which is thereby rendered non-luminous, and no soot is deposited. The oil is contained in a brass reservoir fitted with a pump, *C*, like a bicycle pump. The burner has a very fine jet like that at the base of the Bunsen, and the tube with air-holes is above it at *B*. *A* is a metal cup in which a little methylated spirit is burned in order to vaporise some of the oil. As soon as the flame of the spirit goes out, air is pumped into the reservoir, forcing oil up to the heated jet, where it is vaporised, air being drawn in at the same time. The oil vapour and air burn with a hot non-luminous flame, the heat of which is sufficient to keep the jet at the required temperature. The air pressure is kept up by using the pump at intervals. The stove is shown in section in Fig. 35.

The siphon.—The siphon consists usually of a bent tube one leg of which is longer than the other. It is filled with the liquid to be transferred from one vessel to another, and while both ends of the tube are kept closed, the shorter limb is placed into the vessel of

liquid. The result is that the liquid flows until the level of the liquids is the same in both vessels, or the higher liquid has been siphoned to the lower level.

Suppose a siphon having limbs of equal length to be placed with the ends in two jars containing mercury at the same level, as in Fig. 36, *A*. Let each tube have a length of 30 inches, and let the surface of the mercury in each vessel be 12 inches from the bends of the tube. Under normal conditions the atmosphere is able to support 30 inches of mercury, but in the case illustrated the height of the mercury columns is only 12 inches. There is thus a surplus atmospheric pressure equal to 18 inches of mercury acting on the surface of the mercury in the jars; but as it is the same in each, the mercury in the bent tube does not move.

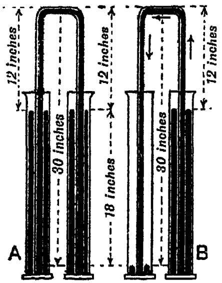


FIG. 36.—To explain how the action of a siphon depends upon atmospheric pressure.

But now consider the conditions represented in Fig. 36, *B*. The 30 inches of mercury in the left-hand tube just balances the atmospheric pressure on the surface of the mercury into which it dips. On the right-hand side, however, the mercury column is only 12 inches high, so there is a surplus atmospheric pressure equal to 18 inches of mercury. The mercury is therefore forced through the tube, and the flow goes on until the level is the same in each vessel. It is thus seen that **the pressure tending to push the liquid up an arm of a siphon is equal to the atmospheric pressure minus the pressure due to the liquid in that arm.**

Since the instrument depends upon the pressure of the atmosphere for its efficiency, it is clear that if the bend of the siphon is at a greater height above the level of the liquid than that which can be supported by the pressure of the atmosphere, then the siphon will not act.

When the liquid is water, the height of the bend above the higher liquid surface may be so great as 34 feet, but when mercury is being transferred by a siphon, this height must be less than 30 inches.

PRACTICAL WORK

1. Syringe.—Dip the open end of a glass syringe into a tumbler of water; pull up the piston, and observe that the water follows it, owing to the pressure of the atmosphere upon the surface of the water in the tumbler.

2. Siphon.—(*a*) Make a siphon by bending a glass tube in a flame; make one limb about 6 inches long and the other at least a foot. Fill the siphon with water, either by placing it in a bucket of water and covering each open end with one of your fingers before lifting it out; or by sucking water through it as when using a pipette. Allow the siphon to empty itself; from which end does the water flow?

Fill the siphon again; dip the short arm in a beaker of water, and notice what occurs when you take your finger from the long arm. Fill the siphon again and let the water flow into a tall narrow vessel. Keep the beaker full of water and notice when the flow of water stops.

(*b*) Connect two short pieces of glass tubing with india-rubber tubing. Fill the tubes with water, and insert the ends below the surface of water in beakers about half full. Lift one of the beakers, and notice the flow of water which takes place. Show that no flow occurs when the level of liquid is the same in both vessels. Test whether flow takes place when the bend of the india-rubber is below the lower of the two vessels (Fig. 37).

Observe whether a siphon will act if there is a hole in it.

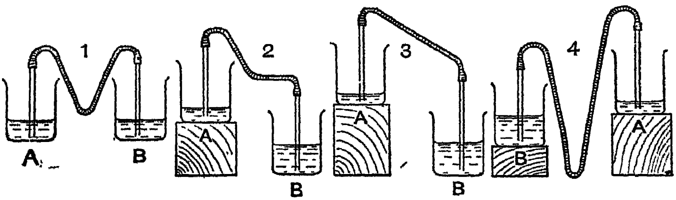


FIG. 37.—In (1) no flow occurs; in (2), (3) and (4) the flow is from *A* to *B*.

CHAPTER V

EFFECTS OF HEAT. THERMOMETRY

Change of size.—Most things, whether solid, liquid or gaseous, get larger when heated and smaller when cooled. The change of size which a thing undergoes is spoken of as the amount it expands or contracts; or heat is said to cause **expansion** in the thing, and the amount of expansion under the same conditions differs for different substances. This expansion is regarded in three ways. Solids undergo increase in length, expansion in area, and expansion in volume. Liquids and gases undergo only expansion in volume. Similar terms can be used with reference to **contraction**, which is the term used to describe a decrease in size.

Expansion of solids and liquids.—The expansion in length of a metal rod can be readily shown by the apparatus illustrated in Fig. 38. The rod is fixed at A, and against the other end there

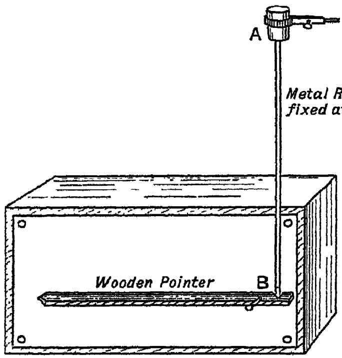


FIG. 38.—Experiment to show the linear expansion of a rod by heat.

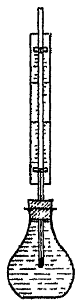


FIG. 39.—An arrangement for showing that liquids increase in volume when heated.

ests one end of a light wooden pointer loosely pivoted at B. On eating the metal rod, it expands, pushing down one end of the ointer and causing the other end to rise. On allowing the rod to ool, the pointer returns to its original position.

To show the effect of heat on a liquid such as water, a small flask ; filled to the top and a cork carrying a glass tube is fitted into it ɔ that some water is forced up the tube (Fig. 39). Warming the ask even with the hands will generally be sufficient to cause the vater to rise in the tube, showing that it has expanded.

The expansion of a gas such as air can be shown with similar pparatus. The flask is fitted with a cork carrying a glass tube, nd inverted so that the tube dips into water ı a beaker (Fig. 40). On heating the flask arefully, the air it contains will expand, and ome will be forced out of the tube through he water. On cooling it, the air inside the ask will contract, and a little water will be rawn up the tube. On alternately heating nd cooling the flask, the water-level in the ube will move down and up, indicating xpansion and contraction.

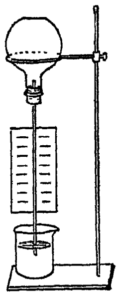


FIG. 40.—When the flask is warmed, the air in it expands and pushes its way out of the tube through the water in the beaker.

Measurement of change of temperature.—Change of temperature means change in the tate of hotness of a body. The change of size which takes place when a thing is heated rovides a means of measuring the change f temperature which it undergoes. An instrument used for this purpose is called a **thermometer**. Usually a hermometer consists of a thick-walled glass tube or stem with a ery small bore, to which is attached a short piece of thin-walled ube with a much larger bore. The end of the thin-walled tube is ealed, and mercury introduced into it, filling it and also part of he small-bore tube. By this means a considerable volume of mercury is available, and its expansion is readily shown by movement of the mercury in the small-bore stem. The upper end of the stem s sealed up to prevent the entrance of dust.

Mercury and spirit thermometers.—There are many reasons for lecting mercury as the liquid for an ordinary thermometer. Its vel can be seen easily; it does not wet the thermometer tube or ick to it; it expands a considerable amount for a small rise of mperature; it is a good conductor of heat, and consequently it

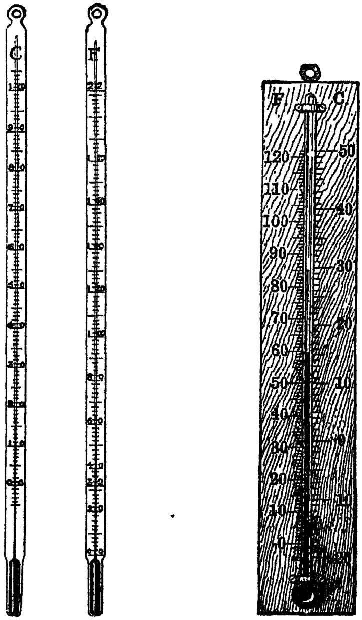


FIG. 41.—Two chemical thermometers, and a room thermometer, with Fahrenheit and centigrade scales.

sumes quickly the temperature of the body with which it is in ntact. Very little heat is required to raise its temperature, and ere is therefore little loss of heat due to warming the thermometer. nother liquid often used is coloured alcohol (formerly called spirits of wine"), which is particularly valuable for measuring mperatures below that at which mercury would be frozen; but ice it boils at a temperature much below that of water, an alcohol

or spirit thermometer cannot be used to measure temperatures much above that of the ordinary room.

Thermometer scales.—For the sake of comparing easily different people's observations and experiments, it is necessary to graduate all thermometers in the same way. Thermometers are usually divided up in one of two ways—(1) the centigrade scale, (2) the Fahrenheit scale.

The centigrade scale.—Here the freezing point is called *zero* or *nought degree centigrade,* written 0° C. The boiling point is called *one hundred degrees centigrade,* and is written 100° C. The space between these two limits is divided into 100 parts, and each division is called a *centigrade degree.*

The Fahrenheit scale.—On thermometers marked in this way the freezing point is called *thirty-two degrees Fahrenheit,* written 32° F., and the boiling point *two hundred and twelve degrees Fahrenheit,* written 212° F. The space between the two limits is divided into 180 parts, and each division is called a *Fahrenheit degree.*

Conversion of thermometer scales.—The Fahrenheit temperature corresponding to a given temperature on the centigrade scale may be calculated as follows. Since there are 100 equal divisions between the freezing point and boiling point on the centigrade scale and 180 on the Fahrenheit scale, one centigrade division = 1·8 Fahrenheit divisions, so that, if centigrade degrees are multiplied by 1·8, or $\frac{9}{5}$, the result is the number of degrees above the Fahrenheit freezing point. Since the freezing point is 32°, this number must be added to the quantity obtained in order to give the Fahrenheit temperature.

For example, it is required to find the Fahrenheit temperature corresponding to 90° C.

$$90 \times \tfrac{9}{5} = 162, \qquad 162 + 32 = 194^\circ \text{ F.}$$

To convert Fahrenheit temperatures to centigrade, first subtract 32 and then multiply by $\frac{5}{9}$.

For example, it is required to find the centigrade temperature corresponding to 86° F.

$$86 - 32 = 54, \qquad 54 \times \tfrac{5}{9} = 30^\circ \text{ C.}$$

The clinical thermometer.—For the measurement of the tempera ture of the body, what is termed a **clinical thermometer** is used (Fig 42). As the temperature of the living human body in a state o

FIG. 42.—A clinical thermometer.

health is never many degrees above or below a temperature of 98° F., a clinical thermometer is only graduated from about 95° F to 110° F. When the bulb of such a thermometer is put under the tongue, or in the armpit, of an adult in good health, and left there for half a minute or so, it will be found, on taking it out, to indicate a temperature between 97·8° F. and 98·6° F. The thread of mercury in the stem of the thermometer remains in one position, though the air is cooling the mercury while the thermometer is being read. This is because of the constriction at the top of the bulb, which causes the thread of mercury in the stem to be left behind while the mercury in the bulb contracts. To " set " the thermometer for a fresh observation, it is only necessary to jerk it sharply, when the thread of mercury will again join up to the liquid in the bulb.

The body may feel hot or cold at different times, but its actual temperature varies only very slightly, whether a person in good health is at the hottest or coldest parts of the earth, eating or fasting, at rest or taking violent exercise. In a fever, however, the temperature of the patient may rise to 105° F., or even higher.

Effects of expansion.—The expansion which substances undergo when heated has often to be taken into account. Railway lines, for example, are laid with a little space between the ends of each length of the rails, so that the rails can expand without meeting when heated. Steam pipes used for heating rooms also are not firmly fixed to the walls at both ends, but left slightly loose or are loosely jointed, so that they can expand or contract without doing damage. For the same reason, the ends of iron bridges are not fixed to the supports upon which they rest, and large iron girders used in buildings are not rigidly secured to the masonry. The bars of a furnace

also fit loosely in their framework in order to allow room for expansion when heated. An iron tyre for a cart wheel is made slightly smaller than the wheel; the tyre is heated to make it expand to fit over the wheel. While still hot, it is slipped over the wheel, and as it cools, it contracts and clasps the wheel very tightly. The inner tube of a pneumatic tyre may burst owing to the expansion of the air inside it in very hot weather. Hence motor-cars and bicycles should be stored in the shade.

The cracking of thick glasses when boiling water is poured in them is explained as follows: The part of the glass with which the hot water comes in contact is heated and expands; but the heating is confined to one spot, because glass does not allow heat to pass through it readily. It is the local expansion of the glass, while the remainder retains its size and shape, which results in the cracking of the vessel. On the other hand, as silica expands only very slightly when heated, a flask constructed of this substance may be made red hot in a flame and then plunged into cold water without cracking.

Platinum and glass both expand to the same extent on heating and contract to the same extent on cooling. Hence it is easy to seal a platinum wire into glass, whereas another metal such as iron is unsuitable, as owing to unequal contraction the glass will crack at the join on cooling.

Expansion of solids and liquids.—Most solids expand when heated, but different solids expand to different extents. If a double strip of metal consisting of a strip of brass riveted to a strip of iron is heated (Fig. 43) it curls over, due to the fact that brass expands more than iron for the same rise of temperature.

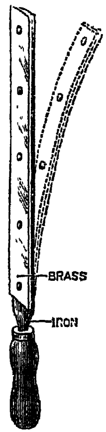


FIG. 43.—Unequal expansion of metals.

The length of a clock pendulum, and therefore the rate at which the clock goes, depend upon the temperature. By making use of the fact that different metals expand to different extents, various devices have been invented for obtaining a pendulum

the length of which does not alter with change of temperature, and thus gives a uniform rate of swing.

In the mercurial pendulum (Fig. 44), the pendulum rod is of metal and a vessel containing mercury is screwed to the lower end of the rod. In hot weather the rod expands downwards, while the mercury expands upwards, and the quantity of mercury is adjusted so that the effective length of the complete pendulum remains the same; this maintains the rate of the clock constant whatever the changes of temperature may be.

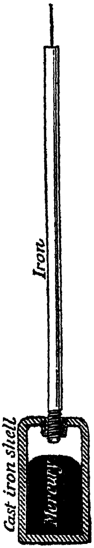


FIG. 44.—Mercurial pendulum.

Liquids, like solids, do not all expand to the same extent for the same rise of temperature. Alcohol expands more rapidly than either mercury or water, but whereas the two former expand uniformly—that is, by the same amount for each degree rise in temperature—water does not expand or contract uniformly at low temperatures and so is unsuitable for use in a thermometer.

Expansion of gases.—It has been seen that air expands on heating and contracts on cooling, and the same is true of all gases. In the case of solids and liquids, different materials expand to different extents; brass, for example, expands more than iron for the same rise of temperature, and turpentine expands more than water. All gases, however, expand to the same extent when heated. This fact was discovered independently by **John Dalton**, an Englishman, and by **J. A. C. Charles**, a Frenchman. Compared with the expansion of solids and liquids, for the same increase of temperature, the expansion of gases is very large.

Anomalous expansion of water.—Most substances expand steadily when heated and contract when cooled. At certain temperatures, water is an exception to this rule. The first effect of cooling warm water is to make it get smaller in volume, or contract. This goes on steadily until the temperature of 4° C. is reached. From this

point, if the cooling is continued, the water no longer contracts, but begins to *expand*. This expansion continues until the temperature 0° C. is reached, when the water begins to change into solid ice, which is much larger in volume than the water from which it is formed.

Conversely, if some water be taken at a temperature of, say, 1° C. and allowed to get warmer, it will steadily get *smaller* in volume up to a temperature of 4° C., but after this temperature is reached the volume will increase as the temperature rises until the water boils.

If the volume of a body gets less while its mass remains the same, then the density of the body must get greater. Since the same mass of water gradually gets smaller and smaller in volume as it is cooled down or warmed up to 4° C., its density becomes greater and greater as the temperature approaches 4° C. This temperature (4° C.), at which a given volume of water weighs more than the same volume at any other temperature, is known as the temperature of the **maximum density of water.**

Results in nature of the peculiar expansion of water.—From a consideration of these facts one can understand what happens when the water of a pond is gradually cooled on a frosty night. As the temperature of the water at the surface gets lower, the water there contracts and is consequently denser. It sinks, and its place is taken by warmer water from below. The same cooling and sinking of the surface water continues until the temperature of the whole of the water is 4° C., at which temperature it has its maximum density, and consequently when the water at the bottom of the pond reaches this temperature it remains where it is. After the temperature of the water at the surface has reached 4° C., any further cooling causes it to expand and get lighter, and this continues until 0° C. is reached.

At 0° C. further cooling causes the surface water to freeze, becoming ice. It is well known that ice floats in water, so still more cooling produces more ice at the surface only, and it is only at times of severe cold that the whole of a pond becomes ice. Water at its maximum density, and at a temperature of 4° C., remains below the ice, and in it much plant and animal life can survive.

Since ice floats, its density must be less than that of water ; in other words, expansion takes place when a volume of water becomes ice. This expansion has been measured, and it has been found that 1 c.c. of water forms 1·09 c.c. of ice. This effect has important consequences in nature. When water in the crevices of a rock freezes, the expansion forces the surfaces of rock apart as if a wedge had been driven in. Each crack so formed makes a space for more water, so that rock is gradually broken up into small particles which go to make up a soil.

The farmer uses this effect in preparing the soil for sowing seed. After ploughing, the surface consists of big lumps of soil. A frost freezes the water in the soil, and the soil particles are thus forced apart. Then when the films of ice melt, the big lumps of soil are easily broken up, giving a good surface ready for planting seeds. The same effect can also produce disastrous consequences in a forest, where the water in the woody tissues of the trees may be frozen and the trunks split open in a way which will reduce considerably their value as timber, or may even cause the death of many trees.

States of matter. Solids, liquids, gases.—The fact that there are three kinds of material things is well known. To this another idea must be added, namely, that **the same matter can exist in three different states.** Ice, water and steam are the same form of matter in the solid, liquid and gaseous state respectively ; and one state passes gradually into the other as the conditions are changed.

With other substances the changes from the solid to the liquid, or from the liquid to the gaseous state, are not always the same as in the case of water. When solid iodine is heated, it appears to pass suddenly from the condition of a solid to that of a gas. Camphor is another example of this sudden change from solid to vapour. When, on the other hand, sealing-wax is heated, it gradually passes into the liquid condition, and may be obtained in a kind of half-way stage—neither true solid nor true liquid.

There is no hard and fast line between these three conditions of matter. Intermediate states of matter are known between those described, but for the present it will be best to confine the attention to this simple division. Some of the special properties of solids,

liquids and gases have now been studied, and it should be noted that although they all have some properties in common—for example, they all have weight, all exert pressure, and all change in volume on heating—yet, whereas all gases expand to the same extent for the same rise of temperature, solids and liquids do not follow this rule ; gases and liquids exert pressure in all directions, solids only downwards.

Methods of cooling.—On a small scale, cold is often produced by means of *freezing mixtures.* When most metallic salts go into solution there is an absorption of heat which varies considerably with the nature of the solute.

The following are some of the mixtures which may be used :

Substances	Parts by weight	Reduction of temperature
Sodium sulphate - - -	8	+10° to −17°
Hydrochloric acid - - -	5	
Pounded ice or snow - -	2	+10° to −18°
Sodium chloride (salt) - -	1	
Sodium sulphate - - -	6	+10° to −26°
Ammonium nitrate - -	5	
Dilute nitric acid - - -	4	

PRACTICAL WORK

1. Kinds of thermometers.—Examine a thermometer of the kind used to indicate the temperature of the air or of a room. Notice that the instrument is sealed up at the top, and that divisions or graduations are marked upon it, so that the height of the mercury in it may be seen easily. These divisions are called *degrees.*

Let the thermometer hang freely in the air of a room for a short time, but not in direct sunlight, and find the temperature of the air indicated by it. Then place the thermometer upon a table, and see whether the same temperature is indicated.

2. Thermometer scales.—Heat some water in a beaker until its temperature reaches boiling point. Place in it a centigrade and a Fahrenheit thermometer and write down the temperature indicated by

each. Remove the flame and allow the water to cool. When the temperature has dropped 5° C., again write down the two readings. Repeat this for every 5° fall of the centigrade thermometer, and get as many results as possible. Arrange them in parallel columns. What do you notice?

3. **Temperature graph.**—On a piece of squared paper draw lines *OA* and *OB* at right angles. Starting at *O*, mark centigrade degrees along

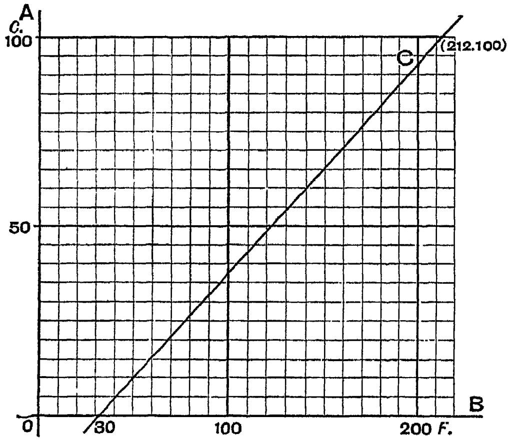


Fig. 45.—Temperature graph.

OA from 0° to 100°. Mark Fahrenheit degrees along *OB* as shown in Fig. 45. Take a pair of results which you have found to correspond in Expt. 2, say 95° C. and 203° F. Through the points on *OA* and *OB* representing these temperatures draw lines parallel to *OB* and *OA*. Mark the point *C* where they meet. Do the same for all of your results. Join up all the points of intersection. The result should be a straight line as in Fig. 45. Using this graph, how would you find the Fahrenheit reading corresponding to any given centigrade temperature and *vice versâ?*

4. **Unequal expansion of liquids.**—Obtain three small flasks of equal capacity and fit each with a rubber stopper and a piece of narrow glass tubing, as in Fig. 39, p. 40. Fill them with water, alcohol and olive oil or turpentine respectively, and press in the stoppers so that no air remains in the flasks. Place the flasks in a vessel of water at the ordinary temperature. By pouring hot water into the vessel, gradually raise the temperature of the liquids and note that they do not all expand at the same rate.

CHAPTER VI

TRANSFERENCE OF HEAT, AND ITS CONSEQUENCES

Conduction of heat.—It is well known that if one end of a metal rod or a poker is placed in a fire, the end not in the fire soon begins to feel warm, and as time goes on it gets warmer and warmer, until it can be held in the hand no longer. Heat has passed from the fire along the rod, or has been **conducted** from the fire by the rod. The process by which heat passes from one part of a body to the next is called **conduction**, and the body along which it passes is known as a **conductor of heat.**

Those substances which easily transmit heat in this way are called *good conductors*, while those which offer much resistance to the passage of heat are called *bad conductors*. Metals are, as a rule, good conductors of heat, but some metals conduct heat better than others. Silver is the best conductor of heat among the metals; lead is comparatively a bad conducting metal.

Wood is a poor conductor; hence tools which have to be heated are often provided with wooden handles. Thus a soldering "iron" consists of a pointed piece of copper to which is fastened an iron rod fitted into a wooden handle. The handles of a metal vessel which has to hold hot water or other liquid are often separated from the vessel by discs of some bad conductor, or have to be wrapped round with non-conducting material, so that the vessel can be held without discomfort.

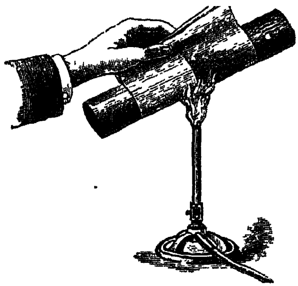


FIG. 46.—Effect of different conductivities of wood and metal.

Fig. 46 represents an experiment to show that wood is a bad conductor

of heat as compared with metals. A single layer of paper is wrapped tightly round a rod consisting partly of metal and partly of wood. If this be moved to and fro in a flame, the paper touching the wood is scorched much sooner than that touching the metal. This is due to the heat transmitted through the paper being conveyed away by the metal more readily than by the wood.

Fig. 47 illustrates an experiment in which a combustible mixture of coal gas and air rising from a Bunsen burner is ignited above a piece of wire gauze held over the burner without the ignition proceeding downwards through the gauze. The mixture of gas and air, like all combustible substances, will not commence to burn unless it is heated up to its "temperature of ignition". In this experiment, the gauze conducts away the heat of the flame, and prevents the mixed gases which are passing through its meshes from being heated to the temperature of ignition. In a short time the gauze may become heated to dull redness, and the flame will then pass through to the top of the burner.

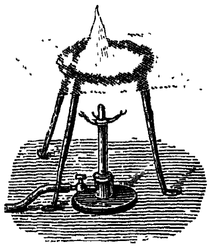


FIG. 47.—Principle of the Davy safety lamp.

The principle illustrated by this experiment is applied in the Davy safety lamp used by miners. The top of the lamp glass is surrounded by a wire gauze cylinder of close mesh. When the atmosphere of the mine contains explosive gases, these gases ignite at first within the gauze cylinder, and the appearance of the flame, due to these gases burning, warns the miner of danger. So long as the gauze remains relatively cool, the gases surrounding the lamp will not be ignited, but if it becomes hot or the flame is driven through the gauze by a draught, an explosion may occur.

Bad conductors.—Most liquids are bad conductors of heat, though mercury, being a metal, is an exception. Experiments have shown that gases are very bad conductors, the conductivity of air being only about one ten thousandth that of copper.

To keep ice during warm weather, it is sometimes wrapped in flannel or blanket. Because of its loose texture the flannel encloses a quantity of air, which, being a bad conductor of heat, prevents

the passage of heat from the warm outside air to the cold ice inside. In the refrigerator, too, the same principle is used. The actual cooling apparatus is contained within a double-walled box with a space between the walls. This is either left " empty ", as it is called when it is full of air, or it is filled with some other bad conductor, such as the mineral substance *asbestos*. An " ice-box " is similarly insulated, but ice has to be put into it, instead of using the refrigerating apparatus, to produce the necessary cooling.

To lift a hot plate, it is held with a folded cloth, which does not conduct heat readily. Steam pipes and cylinders of steam engines are sometimes encased in a packing of some badly conducting material in order to prevent loss of heat. Similarly, in cold countries, woollen clothing is worn to prevent the loss of heat from the body.

Convection.—The process by which water and other liquids are heated may be studied by heating water into which some solid colouring matter, like cochineal or litmus, has been thrown, in a round-bottomed flask over a small flame, as in Fig. 48. The water nearest the flame is heated, and consequently expands and becomes lighter. It therefore rises, and causes a warm ascending current of coloured water. But something must take the place of this water which rises, and the cold water at the top, being heavier than the warm water, sinks to the bottom and takes the place of the water which has risen. This process is repeated over and over again. This gives rise to upward currents of heated water and downward currents of cool water, until presently the whole of the water is heated. These currents are known as **convection currents**, and the process of heating in this manner is called **convection**.

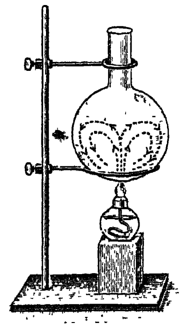


Fig. 48.—Convection currents in a liquid.

Gases are similarly heated by the process of convection, which may be thus defined: Convection is the process by which fluids (liquids and gases) become heated by the actual movement of their parts due to difference of density.

Radiation of heat.—The respects in which *radiation* differs from the other ways in which heat moves from one place to another are :

(1) it travels in straight lines, and

(2) it does not always warm the medium through which it travels.

Although it may not be realised that radiation travels in straight lines, use is made of the fact when the face is screened from the heat of the sun or of a fire. A shady place is sought as a protection from the glare of the sun, because then some object, it may be a tree or a house, is in the straight line between the sun and the body.

Curtains have sometimes been burnt by the sun's rays being concentrated upon them by a glass bottle containing water, though the water is not warmed much by the passage through it of the radiations from the sun. Thus the water in such a case does not pass on its heat after first becoming warm itself. It does not act as a conductor. Yet something must pass through it which can make bodies hot. This something is called *radiation*.

The thermos (vacuum) flask.—A thermos flask is commonly used for keeping a hot liquid hot, but it may also be employed for keep-

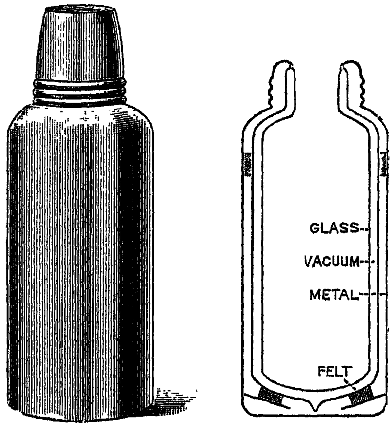


FIG. 49.—A thermos flask. A double-walled glass vessel, with a vacuum between the walls and with the inside surfaces silvered, is an excellent non-conductor of heat. The outer metal case only serves to protect the glass.

ing a cold liquid cold; for example, liquid air is always kept in a vacuum vessel. It consists of a double-walled glass vessel as shown in Fig. 49, the two inside walls having reflecting silvered surfaces. The space between the two glass surfaces is exhausted of air and sealed, so that any liquid contained in the vessel is surrounded by the evacuated space. Heat cannot pass through a vacuum either by conduction or convection. Radiant heat, however, can do so, but loss of heat by radiation is much reduced by the silvered surfaces, which reflects the radiation back. The outer metal case serves to protect the glass, from which it is separated by non-conducting pads of felt or cork.

Ventilation.—The ventilation of ordinary dwelling rooms depends chiefly on the fact that gases become heated by convection. The air in a room is warmed and is made impure at the same time by the presence of people. The impure air rises, and if a suitable opening near the ceiling is made for it to get out, as well as an opening near the floor for the colder, purer air from outside to enter, a continuous circulation of air is set up which will keep the atmosphere of the room pure and sweet.

Small mines are often ventilated by keeping a fire burning at the bottom of one of the shafts. The warm air thus produced rises up one shaft and cold air descends down the other shaft to take its place. Fig. 50 (p. 56) shows an arrangement for producing this effect on a small scale, using two lamp chimneys and a glass-sided box to represent two connected mine-shafts.

The use of lamp chimneys.—Without a chimney the ordinary paraffin lamp gives an irregular smoky flame, which flickers continually owing to the formation of air-currents. When a chimney is used, a steady draught is produced through the perforated metal below the chimney holder. This air is drawn in owing to the formation of convection currents above the flame. Thus, not only is a steady flame produced, but also there is an almost complete absence of soot, owing to the more rapid combustion caused by the indrawn air.

The tall factory chimney serves to carry off waste and harmful products from the furnaces, and at the same time the draught

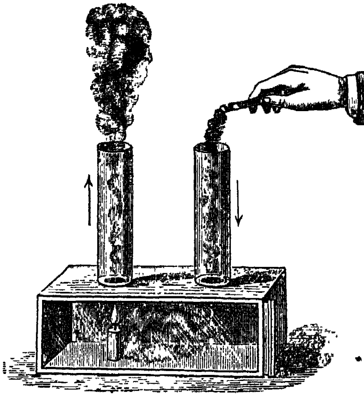


FIG. 50.—Warm air ascends one chimney and cold air descends the other to take its place. The air currents are shown by holding a smouldering taper giving plenty of smoke over the cool chimney.

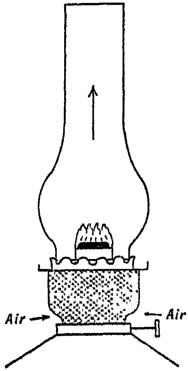


FIG. 51.—Lamp chimney.

produced increases the air supply to the fires and gives more con plete combustion of the fuel.

Winds.—The principal winds experienced are due in part to tl convection currents in the atmosphere. Heated air in the tropi rises and cold air from the polar regions flows in to take its plac The hot air is cooled in the upper atmosphere and moves towar northern and southern polar regions, descending and in due cour moving towards the equator again. The directions of the nort winds in the northern hemisphere and south winds in the southe thus created at the surface of the earth are modified by the rotatic of the earth from west to east. Winds blowing towards the equat become, on account of this rotation, north-east and south-ea winds, while those blowing towards the poles become wester winds. The north-east and south-east winds are the trade win which blow in a steady direction over certai oceans. Over lar regions, these main winds are further mo ied in strength ar direction by mountain ranges and other fa

The land- and sea-breezes which are e nced near the se

coast, especially in the tropics, are local effects (see p. 66). The **south-west monsoon**, with its accompanying rain, is, on the other hand, due to the general circulation of the atmosphere. A region of low pressure exists over the whole of Central Asia, and air from the South Indian Ocean, where the pressure is higher, flows in a south-west to north-east direction towards the low-pressure region. This air travels over some 4,000 miles of sea and is therefore hot and full of moisture. On reaching India it is driven up to heights of 10,000-20,000 feet by mountain ranges and is rapidly cooled. The moisture it contains is condensed and falls as rain, producing the south-west or wet monsoon.

Everyday examples of evaporation.—In hot weather it is not long before a road becomes dry again after having been sprinkled with water. Wet clothes hung exposed to the sun and air soon become quite dry. Streams and rivers, ponds and lakes become shallow, or may dry up completely, unless they receive fresh supplies of water.

It is a common practice to expose shallow vessels of water in rooms which are warmed during winter by stoves. From time to time such vessels have to be refilled, for the water quickly disappears and exists in an invisible form throughout the air of the room, thus preventing the air from becoming too dry.

Perspiration, or sweat, appears as drops of liquid on the face and body on hot days, or when sitting still after active exertion. It soon disappears by passing into the air as vapour.

The process by which, in each of these cases, liquid water is continually being changed into an invisible substance which spreads throughout the air in the neighbourhood, is called **evaporation**.

Humidity.—Air always contains a certain amount of water vapour, the quantity varying with the temperature and depending largely on the presence of great masses of water from which evaporation takes place. When the air can hold no more water vapour it is said to be saturated, and no further evaporation takes place. The *humidity* of the air gives an indication of the quantity of water vapour present, and by "relative humidity" is understood the "degree of wetness". As the temperature of the air is decreased, so the quantity of water vapour it can hold decreases, until a

temperature is reached at which the air is saturated. Any further reduction of temperature causes condensation of water droplets or dew, and the temperature at which this occurs is known as the **dew-point.**

The humidity of the atmosphere is an important factor in nature; many plants will not thrive unless the atmosphere is very full of water vapour, while, conversely, others prefer a drier atmosphere. A certain amount of humidity is necessary to all forms of life. In some industries the humidity of the air is important; a moist atmosphere is necessary for the manufacture of high-class cotton goods. In many cotton mills, the air entering the factory passes through apparatus which makes its humidity and other qualities suitable. This process is termed " air-conditioning ".

Clouds.—When air which is not saturated with water vapour rises, its temperature falls about 1° C. for every rise of 100 metres. As it continues to rise the dew-point is reached, and further rise will cause condensation of water on the nuclei which are present. As the upward movement continues, the temperature falls lower and lower; the amount of water condensed increases, and the drops become larger until a **cloud** is formed.

Rain.—The particles constituting a cloud continually tend to unite together to form larger drops. When these reach a certain size the air can no longer support them, and owing to their increased weight they fall as rain. Water formed in this way—that is, by cooling the vapour as in distillation—is always pure, even though the vapour has come from dirty or salt water. That is why rain-water collected in the open country is pure.

Snow.—Sometimes the temperature of a cloud is below the freezing point of water; it is then impossible for the moisture to assume the liquid state, and it becomes condensed in a solid form. If the temperature of the air through which the solid particles pass is also below the freezing point, a fall of **snow** occurs. The falling particles unite continually to build up larger masses known as **snow-flakes.**

Hail.—When moist air is carried up to high regions of the atmosphere, it condenses into small drops which do not freeze, and at still higher levels snow crystals are formed. The combination of

these two conditions produces hailstones, or hail, which before it falls may have been carried up several times in succession into colder regions of the atmosphere by strong air-currents, each time receiving an additional coat of ice.

Rate of evaporation.—At each temperature a certain amount of vapour present will cause evaporation to cease. The space is then said to be saturated. The amount of vapour that causes saturation is independent of the presence of air. But if a current of air passes over a liquid surface, it carries away with it the vapour that would saturate the space, and evaporation never ceases as long as any liquid is left.

At low temperatures less water vapour is required to produce saturation than at higher temperatures, so that when warm air containing a large quantity of moisture is cooled, some of the vapour separates out as liquid water in the form of dew, cloud, fog or mist.

Different surfaces as radiators and absorbers of heat.—If equal quantities of hot water are poured into a series of tin cans which differ only in the fact that one is brightly polished, another is painted white, another black, and another is coated with lamp-black, and the temperatures of the water, which were originally the same, are taken after about 20 minutes, it will be found that the water in the brightly polished tin has the highest temperature and that in the tin covered with lamp-black the lowest temperature. Clearly the dull black surface of the latter tin has permitted the greatest loss of heat. The dull black surface has radiated more heat than the black painted surface, and this again has radiated more heat than the white painted surface.

A similar experiment can be arranged to investigate the amount of heat absorbed by these same surfaces. The tins are filled with cold water and placed before a closed stove or above a heated iron plate for about 20 minutes. Then it will be found, by taking the temperature of the water in the cans, that the dull black surface has absorbed the most heat and the bright surface the least.

From this it is clear that polished surfaces and light-coloured surfaces are poor radiators and poor absorbers of heat, whereas dull and dark-coloured surfaces are good radiators and good absorbers.

These facts have important consequences in nature. The snow on high mountains receives plenty of radiation from the sun, but it is reflected rather than absorbed by the shining white snow at the mountain top and the snow does not melt. Water vapour in the atmosphere also has an important effect. It serves as a "blanket", preventing the radiation of heat. At the height of mountain tops, there is little water vapour, and any heat absorbed is quickly radiated away and lost. Desert regions are covered with light-coloured sand; the sand absorbs little of the radiation falling on it, which is reflected back from the surface and heats air above it, thus producing very high atmospheric temperatures during the day; at night the sand gives up its heat comparatively slowly, and in consequence the atmosphere may become intensely cold.

Dew is another natural phenomenon depending on the radiating power of surfaces. Dew is formed at night when the temperature of the air in contact with the earth becomes so low that it can no longer hold all the water vapour it contains. Some of the vapour is condensed and deposited as droplets of water on solid objects such as stones, edges and points of leaves, etc. It has also been found that a cloudless sky favours the formation of dew. Here we have the uneven dark-coloured surface, represented by stones and leaves, radiating heat so well that the temperature of the air in contact with it falls until water vapour is condensed upon it; this effect is most pronounced when there are no clouds in the sky to reflect back the radiation. It is also necessary that there should be little wind, for wind would remove the cooled air from the surface of the earth before it reached the dew-point.

Man also makes use of the different radiating and absorbing powers of substances. White, or light, suits are cooler for wear in hot climates than dark clothes, for they absorb heat less readily. Similarly, the outer walls of buildings are sometimes made light in colour to reduce absorption of heat. On the other hand, where rooms are heated by hot-water radiators, the exposed pipes and the radiators themselves are frequently painted with dark paint to assist radiation. Reference has already been made to the silvered walls of the vacuum jacket of the thermos flask (p. 54).

PRACTICAL WORK

1. **Metals conduct heat.**—Take three rods *A*, *B* and *C* of copper, brass and iron, each 4 mm. in diameter and about 40 cm. long. A short piece of one rod is bent at right angles and the three rods are bound together with thick copper wire at *D*. Cover the rods with paraffin wax by means of a brush. Place them on a tripod *E*, with a piece of asbestos between each rod and the tripod. Now heat the junction at *D*. Note that the wax melts along each rod and after a time ceases to melt. Compare the distances along which the wax has melted on each rod.

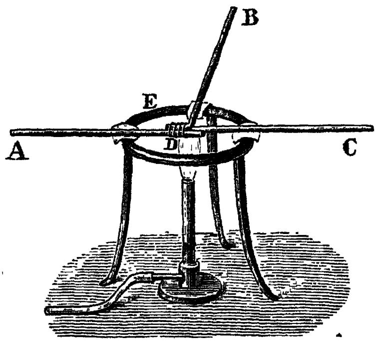


FIG. 52.—Copper, brass and iron rods heated by a bunsen flame show difference of conductivity.

2. **Metals are good conductors.**—(*a*) Turn on, but do not light, a gas jet. Hold over it a piece of wire gauze, and light the gas above the gauze. Notice that the flame does not strike through. Vary the experiment by lowering a piece of cold wire gauze upon an ordinary Bunsen flame. What happens?

(*b*) Hold the wire gauze over a candle flame. Does the flame go through? Note the smoky gas escaping. Is it inflammable?

3. **How liquids are heated.**—Heat over a small flame a round-bottomed flask full of water, as in Fig. 48. Drop into the water some solid colouring matter, like cochineal, aniline dye, litmus, etc. Notice how the hot, coloured water ascends. The movement of the water can also be shown by dropping fine sawdust into the flask.

4. **Evaporation at ordinary temperatures.**—Put some water in a shallow basin or saucer. Determine the weight of the basin and water. Place the basin, with the water in it, in an exposed place free from dust. Determine its weight every day by weighing. Notice that the weight daily decreases. What has become of the water which has disappeared?

5. **Radiation from the sun.**—Focus the rays of the sun upon a piece of paper by means of a reading glass. This can be done by placing the reading glass between the sun and the paper and moving the glass until the brightest image of the sun is obtained. Notice that the paper is burnt and that the glass itself is not heated to the same extent.

6. **Effect of surface upon radiation and absorption.**—(*a*) Obtain two similar small bright tin cans, and fit into each a cork having a hole

through which a thermometer will pass. Cover the outside of one of the vessels with lamp-black by holding it over a candle or luminous gas flame. Put the same quantity of hot water at the same temperature in each and then cork up the vessels, each cork having a thermometer through it so that the bulb is well immersed in the water. Observe the temperature of each vessel of water, and if the temperature of one is higher than that of the other, cool the hotter by adding cold water until the temperatures are equal. Then put the vessels in a cool place where there are no draughts, and after 20-30 minutes again read the temperatures.

(*b*) Similarly pour equal amounts of cold water of the same temperature into a blackened and a bright vessel, and hang them for 20-30 minutes before an even fire or closed stove, or at the same distance above an iron plate, supported on a tripod stand and heated by a burner so that they may be in a position to receive heat equally. At the end of this time observe their temperatures. The blackened vessel will be found at a higher temperature than the bright one. Which vessel *absorbed* more heat? Compare with the vessel which *radiated* more in the last experiment.

CHAPTER VII

QUANTITY OF HEAT. LATENT AND SPECIFIC HEATS

Difference between heat and temperature.—Temperature is not heat; it is only a condition or state of a body, for the body may be cold one minute and hot the next. A hot body is one at a high temperature, a cold body one at a low temperature. If a hot body and a cold body are brought into contact there is an exchange of heat until they are both of the same degree of hotness or coldness—that is, at the same temperature. Hence, temperature may be defined **as a condition or state of a body which is changed by the gain or loss of heat.**

Analogy of temperature with water-level.—If two vessels containing water and arranged at different levels are connected by means of a piece of india-rubber tubing, there is a flow of water from the vessel of water at the higher level towards the vessel at a lower level. This is a consequence of a property of liquids which makes all their particles move as near the lowest point of the container as possible and produce a horizontal upper surface. The flow of water continues until the water in the two vessels is at the same level. This is a similar state of things to that of a hot and cold body in contact. In one case there is a flow of water until the level is the same in the two vessels; in the other there is a passage of heat until the temperature of the two bodies is the same. *Temperature corresponds to water-level.*

Temperature changes when hot and cold liquids are mixed.—Temperature may be regarded as heat-level, so that a hot substance is at a higher heat-level than a colder. Now suppose that a certain weight of hot water is put into one vessel and an equal weight of cold water into another. Equal weights of water will then be at different heat-levels. If the two liquids are mixed together, the temperature or heat-level of the hot water falls, and the temperature

of the cold water rises. The loss of level of one will be equal to the gain by the other, so that the temperature of the mixture will be midway between the two original temperatures. Thus, if the weights of water are equal, and the temperatures at first are 60° C. and 20° C., then the temperature of the mixture will be 40° C. The temperature of the hot water would fall 20° C., and the temperature of the cold water would rise 20° C.

The actual temperature of the mixture would be slightly less than the calculated temperature, because some heat would be lost while the liquids were being mixed. The loss may be regarded as a leakage of heat, and it would, of course, reduce the heat-level of the mixture in the same way that a leak in a water-level apparatus would cause the level after mixing to be less than it would be if the apparatus were perfect.

Quantity of heat in water at different temperatures.—Quantity of heat may be measured by heating effect, so that the quantity of heat in a certain quantity of water depends upon the *weight* of the water and its *temperature*. For any temperature, say 60° C., the amount of heat in 100 grams of water may be taken as twice as great as in 50 grams of water. When equal or unequal weights of water at different temperatures are mixed, the quantity of heat lost by the hot water is the same as the quantity gained by the cold water. Assuming that there has been no loss during the mixing, the fall of temperature of the hot water multiplied by the weight of hot water is equal to the rise of temperature of the cold water multiplied by the weight of cold water.

Unit quantity of heat.—As in all other cases of measurement, a unit quantity is required with which to compare quantities of heat. The unit generally adopted is the **amount of heat necessary to raise the temperature of one gram of water through one degree centigrade.** This unit is called a **calorie.** The amount of heat required to raise the temperature of 2 grams of water through 1° C. is thus 2 calories. Similarly, if 1 gram of water at 0° C. is heated in a test-tube over a burner until its temperature is 1° C., it will have received from the burner 1 unit of heat, or 1 calorie. When the temperature of this 1 gram of water reaches 3° C. it will have received 3 units of heat.

If the tube contains 10 grams of water at 0° C., and its temperature is raised to 12° C., it will have received $10 \times 12 = 120$ units of heat, the number of units being equal to weight (in grams) × increase of temperature (in degrees centigrade).

The number of units of heat taken up by any weight of *water* as its temperature rises, or the amount given out by any weight of *water* in cooling, may be found by multiplying the number of grams of water by the number of degrees, as measured by a centigrade thermometer, through which the temperature rises or falls. This rule may be written as follows:

Number of heat-units = weight of water in grams × number of degress centigrade through which its temperature rises or falls.

Comparison of heat quantities.—The quantity of heat given out by water depends upon (i) the weight of the water, and (ii) its fall in temperature. It might be supposed, therefore, that, as a mass of water falling in temperature gives out a certain quantity of heat, the same mass of another substance falling through the same temperature would give out the same quantity of heat. This, however, is not the case. 100 grams of water cooling 50° C. gives out 5,000 units of heat, but 100 grams of turpentine, mercury, lead, iron, or any other substance cooling through the same temperature as the water, namely 50° C., does *not* give out this number of units of heat. The quantity of heat given out by a substance when its temperature decreases depends not only upon the weight and the temperature, but also upon the substance itself. Similarly, the quantity of heat absorbed by a substance when its temperature rises depends upon its weight, the temperature rise, and the substance itself.

Capacity of water for heat.—Of all known substances, water has the greatest capacity for heat; consequently a larger amount of heat is required to raise the temperature of a given weight of water through a certain number of degrees of temperature than is needed by an equal weight of any other substance.

Thus, suppose a pound of water to be put into one flask and a pound of mercury into another, and that these flasks are then heated for five minutes by two burners which give out the same

quantity of heat. The starting temperature of the two liquids is, say, 15° C. If at the end of the experiment the temperature of the water was 20° C., that of the mercury would probably be about 180° C. The quantity of heat required to raise the temperature of the water through 5° C. will raise that of the same mass of mercury through 165° C.; hence it requires much more heat to raise the temperature of water through a certain number of degrees than it does to raise the temperature of the same mass of mercury by the same amount. Similarly, in cooling through any number of degrees of temperature, a definite weight of water will give out a larger amount of heat than an equal weight of any other substance, the temperature of which falls through the same number of degrees.

Results in nature of the high capacity of water for heat.—Water takes a large amount of heat to warm it; consequently it is heated by the sun's rays only slowly, yet when it cools it falls in temperature

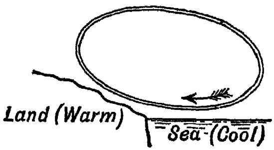


FIG. 53.—Sea-breeze during day.

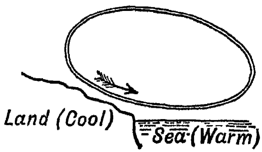


FIG. 54.—Land-breeze after sunset.

just as slowly. The effect of this on the climate of islands is very marked. The winter temperature is never very low and the climate never very severe, because the water surrounding the country acts as a great storehouse, slowly giving up heat to the land. Similarly, the summer temperature is never unbearably hot, because the surrounding water takes so long to warm, and, being always cooler than the land, keeps the temperature of the latter from becoming very high.

Near the sea, especially in the tropics, there are well-marked breezes, which result from the different behaviour towards heat of land and water. Heat received from the sun during the day-time makes the air above the land become warmer than that above the water, and an upward current of air will be set up over the land. The cooler air from over the sea will flow in to take the place of the air which rises and will constitute a **sea-breeze** (Fig. 53).

After sunset both the sea and land begin to radiate heat ; the land being a better radiator becomes cool quickly, but the sea remains warm. The air over the water consequently remains warmer than that over the land, and the pressure above the sea will be lower than that over the land, causing a current of air from the land out to sea, which is known as a **land-breeze** (Fig. 54).

Temperatures produced by mixing various hot and cold substances.—If equal weights of iron and water be heated to the same high temperature, say 100° C., and the iron be plunged into a given weight of water at a lower temperature, say 20° C., while the hot water is mixed with an equal weight of water at 20° C., and the resulting temperatures in the two cases be determined, it is found that the temperature of the mixture of cold water and hot water is considerably higher than that of the equal weight of cold water into which the lump of iron was plunged. Hence, equal weights of iron and water at the same high temperatures do not give out the same amount of heat when cooled. The water at 100° C. gives out a larger quantity of heat than an equal weight of iron at 100° C., because its capacity for heat is greater.

Comparison of capacities for heat of different metals.—When equal weights of water, iron nails, copper wire, and mercury at the same temperature, that of boiling water for example, are each in turn stirred up with equal weights of cold water at the same temperature and in separate beakers, it is found that the heating effect of the water is greater than that of any one of the other substances. This is because the capacity for heat of water is greater than that of any of these (or any other) substances.

The amount of heat required to raise the temperature of one gram of a substance through 1° C. or the amount of heat given out by one gram of a substance in cooling through 1° C., in comparison with the amount of heat taken up (or given out) by an equal weight of water, is known as the **specific heat of the substance.**

The determination of specific heats.—To find the capacity for heat of a substance, a convenient quantity of the substance is usually heated to a definite temperature and then allowed to give up its heat to a known weight of water. If losses through radiation and

other causes are avoided as much as possible, the heat lost by the substance in cooling may be taken as equal to the heat gained by the water in having its temperature raised. The weight and rise of temperature of the water having been observed, this gain of heat can be calculated by multiplying the weight of water by its rise of temperature. The heat lost by each gram of the substance, the specific heat of which is being determined, in cooling 1° C., can then be calculated, and the result is the specific heat required.

Latent heat.—When a mixture of ice and water is heated, heat is being continually given to the mixture. Yet the temperature as recorded by the thermometer gets no higher. What becomes of this heat, as it has no effect upon the temperature of the mixture? The ice is gradually melted, and if the heating is continued long enough it is all changed into water. As soon as this has happened, every further addition of heat raises the temperature of the water. The conclusion is that the heat previously given to the mixture is all used up in bringing about the change of ice into water. Further, it is found that not only in the case of ice, but also when liquid water is turned into a gas (steam), there is no increase in temperature, even while heat is being added, until the whole of the water has been changed into steam.

This amount of heat which is necessary to change a solid into a liquid or a liquid into a gas at the same temperature is spoken of as **latent heat.** The word latent comes from a Latin word, meaning "lying hidden", and refers to the fact that the heat used up in changing a solid to the liquid or a liquid to the gaseous condition has no effect upon a thermometer, but appears to be hidden away in the liquid or gas.

Latent heat of water.—The number of units of heat which are required to change the state of a gram of ice, converting it from the solid to the liquid condition, without raising its temperature, is called the **latent heat of water,** or the **latent heat of fusion of ice.** To melt 1 gram of ice requires 80 heat-units. That is to say, as much heat as would raise the temperature of 1 gram of water through 80° C., or would raise the temperature of 80 grams of water through

1° C., is used up in changing a gram of ice into a gram of water a the same temperature.

Natural consequences of the latent heat of water.—Just as it i necessary, before a pound of ice can be changed into a pound o water at the same temperature, to supply an amount of heat whicl would raise the temperature of a pound of water through 80° C., so before a pound of water can be changed into a pound of ice, precisel the same amount of heat must be taken from it. This is why i requires several cold nights to cover a pond with ice, for not unti every pound of water at the surface has had this large amount o heat taken from it can it change into ice. For just the same reason in countries where snow falls and water freezes, it takes a very lon time to melt completely the snow in the roads and the ice on th ponds, even after a thaw has set in.

Latent heat of steam.—When once water has started to boil, it temperature gets no higher than the boiling point; so long as ther is any water left, no matter how much it is heated, its temperatur remains the same. All the heat is absorbed, or used up, in bringin about the change from the liquid state to that of vapour. It require nearly seven times more heat to convert 1 gram of water at temperature of 100° C. into steam at the same temperature, than i does to change a gram of ice at 0° C. into a gram of water at 0° C Though to bring about the latter change requires an expenditure o 80 heat units, to convert a gram of water at 100° C. into a gram o steam without changing its temperature requires no fewer than 54 heat units.

Thus the **latent heat of steam**, or, as it is sometimes called, the **laten heat of vaporisation of water**, is 540. Expressed in another way, w may say that it requires as much heat as would raise the tempera ture of 540 grams of water through 1° C. simply to bring about th change of 1 gram of water at 100° C. into 1 gram of steam a the same temperature. The amount of heat required to change liquid into a vapour differs with different liquids, but no liquid i ever changed into a vapour without some absorption of heat. Thi is true whether the change takes place quietly in evaporation o rapidly as in boiling.

Just as a large quantity of heat is required to convert water into steam, so a large quantity is given up when steam becomes water. It is for this reason that a scald from the steam of boiling water is worse than a scald from the boiling water itself.

Heat disappears during vaporisation.—When a liquid is changed into vapour, a certain amount of heat is used up. It does not matter whether the liquid evaporates slowly or boils; every part of it requires a certain amount of heat before it becomes converted into vapour. In boiling, this heat is supplied by the flame or fire, and in evaporation it is taken from the objects in contact with the liquid. The faster the evaporation, the more rapidly heat is absorbed. When a liquid evaporates very rapidly, the cooling produced is very noticeable. For example, if a few drops of a volatile liquid such as ether are sprinkled upon the hand, the liquid soon disappears and the hand feels cold. The heat necessary for the evaporation of this liquid is taken from the hand, or from any other things with which it is in contact; consequently the hand becomes cooler and cooler as the vapour is formed. So much heat may be absorbed in this way that water can be frozen by the evaporation of ether in a vessel in contact with it (Fig. 55).

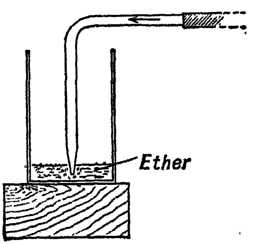


FIG. 55.—By blowing air through ether, in a beaker standing in a thin layer of water, rapid evaporation occurs, removing heat so quickly that the water is frozen.

A practical application of the cold produced by evaporation is the use of porous earthen vessels to hold drinking water in hot countries. The water which soaks through the vessel evaporates, and thus the vessel and its contents keep cool. The same result can be obtained by wrapping a vessel in a wet cloth exposed to a current of air.

Similarly, heat disappears when a gas expands; the gas particles have to do work in order to overcome their attraction for one another. They thereby use up energy and become cooled. This principle is made use of in modern plants for liquefying air and other gases.

On the other hand, if a gas is compressed, its temperature rises;

outside work is done on it and it gains energy, which is made evident by a rise in temperature. Thus, on pumping up a bicycle tyre, it will be noticed that the pump becomes hot.

Boiling.—At low temperatures, evaporation takes place only from the exposed surface of a liquid, and the change from liquid to vapour is invisible. As the temperature is raised, the rate of evaporation increases, and a temperature is reached finally when evaporation takes place anywhere within the liquid as well as from the surface. Bubbles of vapour are formed within the liquid and rise to the surface; the evaporation is then rapid and visible, and the liquid is said to **boil**. If heat be applied to the containing vessel from below, the liquid in contact with the bottom of the vessel is always slightly hotter than the liquid above, hence the bubbles of vapour as a rule appear to form at the bottom of the vessel. For each liquid, *at atmospheric pressure*, there is a definite temperature at which this visible evaporation takes place within the liquid as well as from the surface, and this temperature is termed the **boiling point** of the liquid.

The temperature at which any liquid boils is influenced slightly by the nature of the containing vessel and by the degree of cleanliness of the inner surface of the vessel. Although the temperature of the boiling liquid itself is subject to such variations, the temperature of the vapour immediately above the liquid is constant if the pressure of the air is constant. It is necessary, therefore, when determining the boiling point of a pure liquid, to support the thermometer with its bulb in the vapour immediately above the surface of the liquid.

Water boiling under diminished pressure.—Pressure has a great influence on the boiling point of a liquid. The weight of the atmosphere at the surface of the earth is equal to that of a weight of 15 lb. on every square inch. The amount of atmospheric pressure upon an object depends upon the extent of air above the object. This pressure is less at the top of a mountain than at the bottom, and consequently the pressure of the air in the former situation is less than in the latter. To boil a liquid when the pressure of the atmosphere is high, it is necessary to heat the liquid more than when the

pressure is low. The liquid being heated more, its temperature will get higher before there is any conversion into vapour, and consequently its boiling point will be higher when the pressure is greater. Conversely, at the top of a mountain the boiling point is lower than at the bottom. On this account, on a high mountain, water cannot be made hot enough, when boiling in an open vessel, to make tea or cook an egg. In finding the boiling point of a liquid, the pressure of the atmosphere at that time and place must therefore be known.

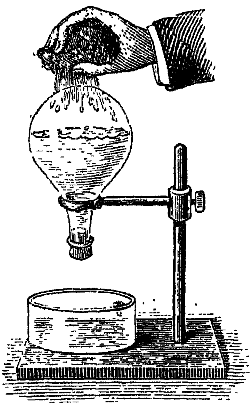


FIG. 56.—Water boiling under diminished pressure.

A simple experiment proves that water may boil at a temperature considerably below 100° C. when the pressure upon its surface is diminished. Some water is boiled in a round-bottomed flask and allowed to continue boiling for some minutes so that all the air above the water in the flask is driven out and its place taken by steam. The flask is then removed from the flame and a cork inserted as quickly as possible. After standing to cool for a short time when the temperature can no longer be 100° C., the flask is turned over and cold water poured upon it, or a cold wet sponge is squeezed upon it as shown in Fig. 56. This procedure causes the steam in the flask to condense, and, as no air can get in, the pressure on the surface of the water is now less than it was before, and the water is seen to boil again quite briskly.

PRACTICAL WORK

1. Distinction between temperature and heat.—Half fill a beaker with water and heat it. Place in the beaker a test-tube containing water. After heating for a little time, observe the temperature of the water in the test-tube and surrounding it ; it will be the same. Pour the hot water from the test-tube, and that from the beaker, into equal quantities of cold water from the tap in separate large beakers. The large amount of hot water will be found to have a greater heating effect than

the small amount; hence it must have possessed more heat than the small amount.

2. **Result of mixing hot and cold equal weights of the same substance.**—Put a weighed quantity of warm water in a beaker, and the same weight of cold water in another beaker. Observe the temperature of each by means of a thermometer. Pour the cold water into the hot. It will be found on stirring them together with the thermometer that the temperature of the mixture is about midway between the two original temperatures.

From the observations construct a table like that below, to show that the temperature, produced by mixing equal weights of the same liquid at different temperatures, is equal to half the sum of the temperatures:

Temperature of water A	Temperature of water B	$\frac{A+B}{2}$	Temperature of mixture

3. **Equality of loss and gain of heat.**—Weigh about 200 grams of cold water into a beaker, and observe its temperature. Put about 150 grams of water into another beaker; heat it to about 46° C. Now place the beaker of hot water on the table, with a thermometer in it, and observe its temperature. When the temperature has fallen, to say 40° C., quickly pour the hot water into the cold. Stir up the mixture with the thermometer, and observe the temperature after mixing. Record your observations as below:

Weight of cold water - - - ...... gm.
Temperature of cold water - - ......° C.
Temperature of mixture - - - ......° C.
Number of degrees through which the temperature of the cold water was raised - - - - - - ......° C.
Weight of hot water - - - - ...... gm.
Temperature of hot water - - - ......° C.
Number of degrees through which the temperature of the hot water fell - ......° C.

Tabulate the gain and loss of heat that occur, as shown below:

Gain	Loss
Weight of cold water × its rise of temperature	Weight of hot water × its fall of temperature
.... ×	.... × ....
....	....

The gain will be found to be slightly less than the loss. The difference is due to the fact that the amount of heat required to raise the temperature of the glass of the beaker containing the cold water has not been taken into consideration.

Repeat the experiment using different weights of hot and cold water. Notice that in each case the weight of hot water × the fall of temperature is approximately equal to the weight of cold water × the gain of temperature. The difference shows the amount of heat absorbed by the glass of the cold beaker.

The amount of heat gained by 1 gram of water when its temperature is raised 1° C., or lost when its temperature falls 1° C., is adopted as the unit quantity of heat.

4. Heat capacity of iron and water.—Weigh a ½-litre beaker and add 1-lb. of cold water. Suspend in the water a 1-lb. iron weight as shown in Fig. 57.

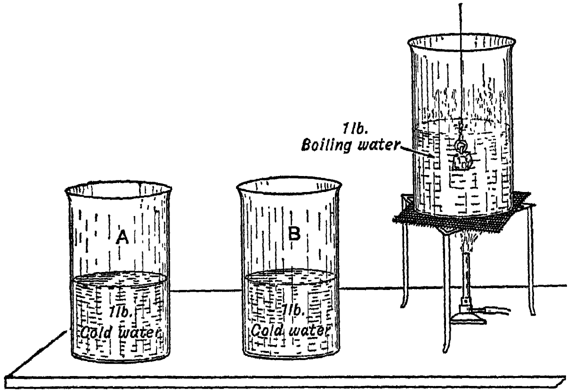


FIG. 57.—Hot water contains more heat than the same weight of equally hot iron. When 1 lb. of hot iron is immersed in the cold water in *A*, the temperature of the latter is raised; but the cold water in *B* is warmed far more when 1 lb. of hot water is poured into it.

In each of two other beakers, *A* and *B*, place 1 lb. of water, and take the temperatures. Now heat the first beaker until the water boils, and quickly transfer the iron weight to *A* and the hot water to *B*. Stir, and take the temperatures. Compare the number of degrees through which the cold water has been warmed in each case.

5. Heat required to melt ice and to boil water.—Place a handful of freshly crushed ice in a metal can, which may be surrounded by an asbestos jacket. Arrange a centigrade thermometer with its bulb in

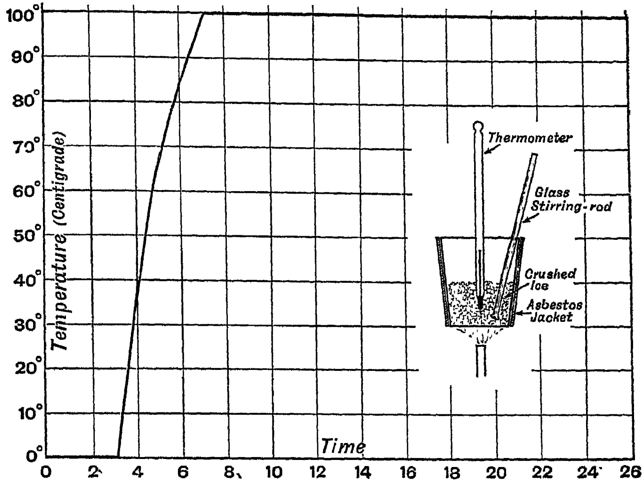


FIG. 58.—The quantities of heat required to convert ice into water, and water into steam. The thick black line shows the effect of a steady flame upon ice contained in a metal vessel. The time required to melt the ice is nearly as long as the time required to raise the water to its boiling point; but the time required to convert the boiling water into steam is much greater than either.

the ice as in Fig. 58. Light a small gas flame under the can, note the exact time when the heating begins, and stir the ice. Note that the thermometer reading remains at 0° C. as long as any ice is unmelted. Note the exact time when the ice disappears. Since there has been no rise in temperature, all the heat given by the burner has been used up in melting the ice. Now read the temperature at the end of each minute, and note the exact time when the water begins to boil. Continue heating, noting that there is no further rise in temperature until all the water is boiled away. Note the time when this happens.

Tabulate results thus:

	Time	Difference
Ice melted - - -	3 min. 0 sec.	——
Boiling begins - -	7 min. 10 sec.	4 min. 10 sec.
All boiled away - -	29 min. 0 sec.	21 min. 50 sec.

Assuming that 1 gm. of ice, forming 1 gm. of water, was used, then 100 calories of heat were used up in raising this gram from 0° to 100° C. and this took 4 min. 10 sec. The quantity of heat supplied by the burner is proportional to the time, and since the ice was melted in 3 min., the

heat used up in the melting $= 100 \times \frac{3}{4\frac{1}{6}} = 72$ calories; and the heat used up in boiling away the water $= 100 \times \frac{22}{4\frac{1}{6}} = 528$ calories. These values are only approximately correct.

6. Evaporation produces cold.—Pour a little ether into a small beaker, and stand the beaker in a puddle of water on the bench. By means of a glass tube inserted in the beaker, and a pair of bellows, blow a rapid current of air through the ether. It quickly evaporates, and the base of the beaker will probably become so cold that the water under it is frozen.

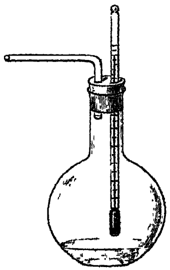


FIG. 59.—Flask with thermometer fitted for observing the boiling point of water.

7. Boiling point of water.—(*a*) Boil some distilled water in a flask (Fig. 59) having a thermometer arranged just above the surface of the water. Notice the temperature, which will be either *one hundred degrees* (100°), or very near it, if a thermometer with centigrade divisions is used.

(*b*) Add salt to the water. Fix a thermometer in the steam of the boiling water, and notice that the temperature is the same as before—namely, about 100°. Push the thermometer into the water, and notice that a higher temperature is indicated.

8. Boiling point and pressure.—Boil some water in a round-bottomed flask, and let it continue to boil for some minutes to drive all the air out of the flask. Remove the burner and quickly insert a well-fitting cork. Allow the flask to cool for a few minutes, then turn it upside down on a suitable support and throw cold water on to the flask (Fig. 56). Notice the water again starts boiling vigorously.

CHAPTER VIII

MECHANICS

Energy.—The power of overcoming resistance or doing work called energy. All moving bodies possess energy. Moving air wind drives round the sails of a windmill and so works the machin of the mill ; it drives along a ship, thus overcoming the resista of the water. The running stream works the mill-wheel, and energy it possessed may be expended in grinding corn. These examples of the energy of moving bodies, or the energy of moti or kinetic energy. **Kinetic energy is the energy of matter in motion.**

Imagine a weight raised from the ground and placed upo high shelf. To place the weight in this position a certain amo of work must be done. Further, just as soon as it is released fr its position of rest, and is free to move, the weight will fall w an ever-increasing velocity until it reaches the ground. On shelf the weight, owing to its position, possessed a certain amo of energy exactly equal to the work expended in placing it th This form of energy is known as **potential energy** ; it is capable becoming kinetic or active when the conditions become suitable.

An ordinary clock, which is driven by a spring, affords an exam of potential energy. The wound-up spring possesses poten energy exactly equal to the amount of work done in winding it This potential energy is being continually converted into kin energy as the spring becomes unwound in working the clock.

Force.—It is common knowledge that things do not move themselves. A body at rest remains at rest until it is forced move. Moreover, if it is moving, it tends to go on moving in same direction and with the same velocity until affected by application of force. In a word, non-living matter is motionl

It does nothing by itself and appears to oppose any change in its condition, whatever that condition may be.

A force may be defined as that which produces motion in a body or alters its existing state of motion. This means, first, that if a body is at rest, it will remain at rest until there is some reason for its moving—until some outside influence, which is called a force, acts upon it. Consider a billiard ball moving steadily on a billiard table. After a time the ball comes to rest, but it moves for a longer time on the table than it would do on a road. The table is smoother than the road, and there is a connection between the roughness or smoothness and the length of time during which the ball moves. If the table could be made smoother and smoother, the ball would move for a longer and longer time; and if both the ball and the table were perfectly smooth, there is no reason why the ball should ever stop. The roughness or friction represents, then, the force which causes the ball to change its state of motion for one of rest.

The force of gravitation.—Experiments and observations made by **Sir Isaac Newton** led him to conclude that it was the rule of Nature for every material object to attract every other object, and that this force of attraction is proportional to the masses of the bodies; a large mass exerts a greater force of attraction than a small mass. But the farther these bodies are apart the less is the attraction between them.

Consider the case of a heavy ball on the top of a house. The earth attracts the ball and the ball attracts the earth. The ball, if free to move, falls to the earth; strictly speaking, however, the ball and the earth move to meet one another along the line joining their centres. But the ball moves as much farther than the earth as the earth's mass is greater than that of the ball; and for practical purposes this is the same as saying that only the ball moves and that the earth remains still.

This force of attraction between all material bodies is called the force of gravitation, but this is only a name. Calling this force "gravitation", and the rule according to which it acts the "law of gravitation", does not teach anything about the nature of the force itself.

Simple balances for weighing.—The attraction of bodies by the earth can be used to measure their **weight**. If a piece of stone be hung upon the end of a coil of steel wire, the coil is made longer by the downward pull due to the action of the force of gravitation on the mass fixed to its end. The amount by which a steel spring is lengthened, as the result of such downward pull of masses attached to its end, is used to measure their weights in the instrument called a **spring balance**. The instrument consists of a steel spring fixed at one end, and with a pointer attached at the other end; the pointer moves over a graduated scale and, provided the spring is not stretched too much by a heavy weight, the amount of stretching is proportional to the weight of the body extending it (Fig. 60). Another form of spring balance, in which movement of the end of the spring causes a pointer to move over a circular scale marked to indicate the weight, is shown in Fig. 61.

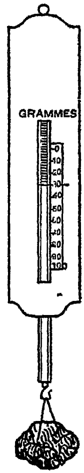


FIG. 60.—A spring balance measures the attraction between a thing and the earth.

The attraction of gravity.—Bearing in mind that weight is really a measure of the attraction between an object and the earth, the weight of a thing which has been carried up in a balloon or aeroplane ought to be less than it is at sea-level, since it is farther away from the earth. This is found to be the case, but, to demonstrate the actual difference in weight, the weight must be measured by a spring balance. The ordinary balance would be useless because the attraction of gravity would have the same effect on each pan, so that the weight would not *apparently* change.

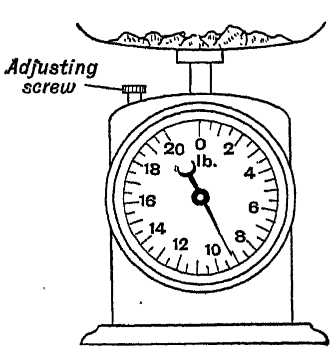


FIG. 61.—A household spring balance.

Friction.—When a rectangular wooden block is resting on a horizontal table, a small force may be applied horizontally to the block—for example, by attaching to it a string fastened to the hook of a spring balance which is pulled in the hand—without causing it to move. The reason for the block remaining at rest is that the force applied to it is neutralised by an equal and opposite force tending to keep the block at rest. This force is located between the two surfaces in contact: it may be considered as a resistance, and is called into play by **friction** between the two surfaces.

When the force is increased gradually, the opposing resistance due to friction must increase at the same rate because the block still does not move. Finally, a certain maximum is reached, which the resistance cannot exceed; if the applied force slightly exceeds this maximum the block begins to move. The magnitude of this maximum force measures what is termed the **static** or **limiting friction.** When motion has commenced, it will be found that a smaller force is sufficient to maintain the body in motion. Hence, the resistance due to friction between two surfaces in relative motion—termed the **kinetic** or **sliding friction**—is less than the limiting or static friction.

In all cases when steady motion has been attained, the pull exerted on the block is exactly equal to the force of sliding friction. All that the pull of the spring balance is doing is to overcome the resistance, and there is no additional moving force. Suppose there were no friction between the block and the board; then the block, once started, would keep on moving without any pull of the spring balance. It is only because there is friction between the surfaces that any force has to be used to overcome it.

Friction between the feet and the ground makes it possible for men to walk; without friction, the feet would not "grip" the ground. Similarly the friction between wheels and the ground or rails makes movement of carts, railway carriages, etc., possible. On the other hand, friction between a wheel hub and the axle on which it turns is not desired, and the **bearing,** as it is termed, is lubricated with oil to decrease the friction. For a similar reason, some bearings are fitted with steel balls (Fig. 62) or rollers, so that the surface of actual contact is small.

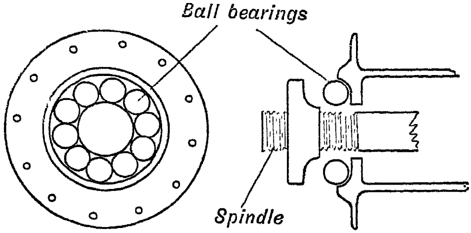


FIG. 62.—End view and section (with spindle drawn out) of one end of the hub of the front wheel of a bicycle, showing position of ball-bearings.

Brakes.—A brake is a mechanical arrangement for checking the motion of one or more of the wheels of a vehicle. In its simplest form it consists of a lever which can be moved by the hand so as to press the brake-block against the wheel (Fig. 63), retarding or stopping the motion of the wheel. On a bicycle, the brakes usually consist of a pair of rubber pads so fitted that they can be pressed against the metal rims of the wheels when it is desired to stop the bicycle. A motor-car brake (Fig. 64) is a band of flexible material made for

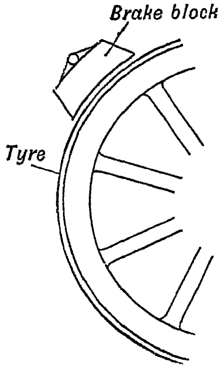


FIG. 63.—Part of a cart-wheel, showing position of wooden brake block.

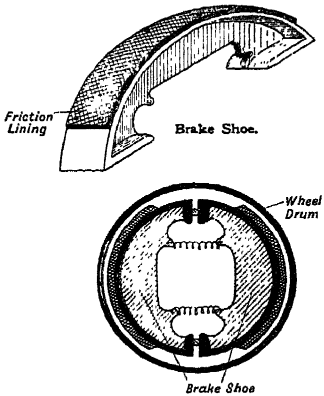


FIG. 64.—Motor-car brake. The two brake shoes, covered with the friction lining, are thrust apart by application of the brake, and are forced against the inside of the wheel drum, thus tending to stop its turning.

the purpose, which can be applied to the inside edge of a drum revolving with the wheels. In every case the brake depends on the friction between a fixed and a moving surface, and special materials giving high friction and good wearing properties have been invented for the purpose.

Work.—Anything at rest is only set in motion by the action of a force upon it; and anything moving only changes the direction of its motion, or its speed, as the result of the action of a force. When a thing moves from rest the continued action of the force upon it causes a continuous increase in speed.

In the case of a thing already moving, though it may be argued that a change of direction or a change of velocity is the result of an external force, the converse statement that an external force acting upon a moving thing causes a change of direction or of velocity cannot be used, for in some instances the force may be entirely occupied in maintaining such motion in opposition to other forces acting upon it. Thus, when a ship is sailing with a uniform speed, the force of the wind is used up in maintaining this velocity by overcoming the resistance of the water.

When a force acts in either of these ways it is said to do **work**—that is, work is done by a force in setting into motion a thing previously at rest and giving it a regularly increasing velocity, or by maintaining a uniform motion in opposition to the action of other forces. The inclusive name of **resistance** may therefore be given to all these forces acting in opposition to the force which is being considered.

The following definition of work is thus obtained: **Work is done when the point of application of a force moves.** All examples of mechanical contrivances, by means of which work is accomplished, come within the scope of this definition, as well as all other cases in which work is said to be done. Consider, for example, a horse drawing a heavy load in a cart along a road. Here the force exerted by the horse is used up in overcoming the resistance due to the road. A man raising a mass from the ground overcomes the resistance due to the thing's weight, and he also does work in raising his own body. Anything falling from a height under the influence of the earth's

attractive force has work done upon it, with the result that its velocity increases uniformly by 32·2 feet per second in every second.

Measurement of work.—The work done in all cases is proportional to the force, and to the distance through which the force acts ; or,

Work = force × distance.

Unit work is done when unit force acts through unit distance.

Unless there is motion no work is done. If a weight is put upon a table or shelf, so long as the weight remains in one place it evidently does no work, though it is capable of doing work by reason of its elevated position.

For practical purposes the unit of work which is adopted is **the work done in moving a mass of one pound through one foot,** and it is called the **foot-pound** ; or, if metric units are employed, **the work done in moving a mass of one gram through one centimetre,** the unit being the **centimetre-gram.**

Work against gravity.—In the case of a thing raised from the earth, the work done is equal to the force required, namely, that equal to the weight of the thing, multiplied by the distance through which it is raised. In calculating the amount of work in such circumstances, it is necessary, in order to find the weight of the thing, to multiply the thing's mass by the value of the attractive force of the earth at the place where the work is done.

PRACTICAL WORK

1. **Illustrations of energy.**—(*a*) Stretch a piece of tissue paper over the top of an empty tin or jar. Carefully place a small coin on the paper, and notice that the paper will support it. Now lift the coin and allow it to drop on to the paper. The coin will probably pierce the paper.

(*b*) Fasten a thin thread to a weight. Notice that the weight can be lifted carefully by the thread, but if, while the weight is suspended, it is lifted in the hand and dropped, the thread will be broken.

(*c*) Note the reading of a spring balance when a weight is attached to it by a string. Lift the weight in the hand and drop it. Observe that the spring balance reading is for a moment much higher than it was when the weight was at rest.

2. **The earth's attraction.**—(*a*) Suspend a spring balance from a firm support. Notice that to bring down the index you must exert a pull

on the bottom hook. The greater the effort exerted, the farther down the scale does the index move.

(*b*) Suspend any convenient mass from the hook of the balance, and notice that the index moves a certain distance down the scale as in the previous experiment. The pull in this case measures the weight of the mass—that is, the earth's attraction for it at the place of observation. Repeat with different masses.

3. Measurement of friction.—(*a*) Fit up a board, *AB*, and slider, *C*, with a cord, pulley and scale-pan as shown in Fig. 65, so that the horizontal force, **P**, required to overcome frictional resistance, **R**, may be measured. Make a number of experiments on the limiting or static friction, using different loads on the slider. In each experiment, place loads carefully into the scale-pan so as to avoid jerks until the slider starts off. The amount of static friction can be determined from the observations.

Using the same loads on the slider, perform the same operations, but help the slider to start by jerking it. Adjust the load in the scale-pan until steady uniform motion, as nearly as you can judge, has been obtained. From these observations the value of sliding or kinetic friction can be found.

(*b*) Repeat the experiments using rough and polished surfaces, and with slider and board coated in succession with cloth, paper and other materials.

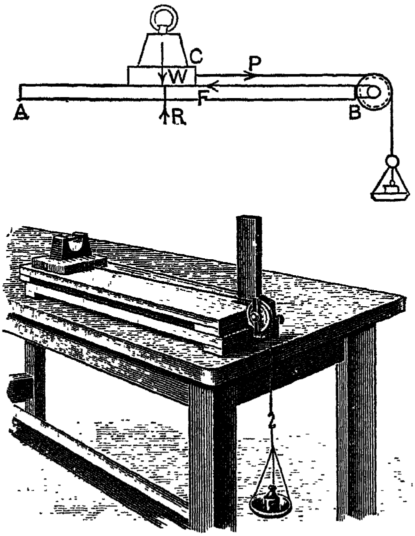


FIG. 65.—Apparatus for experiments on friction.

(c) Determine the amount of friction, for a series of loads, of wood on wood.

4. **Measurement of work.**—Lift a 1 lb. weight through the distance of 1 foot. You thus do one foot-pound of work against the attraction of gravity. Lift other weights through different distances, and in each case, by multiplying the weight by the distance, determine the number of foot-pounds, or units of work performed.

CHAPTER IX

LEVERS, PULLEYS, INCLINED PLANE. SPRINGS

Principle of the lever.—If a wooden rod is balanced on a wire pass through its middle point, and equal weights are slung from the r at equal distances from its middle point, then the rod is fou to remain balanced horizontally (Fig. 66). This is a simple illust

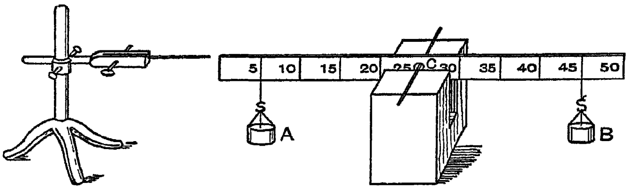


FIG. 66.—A simple balance.

tion of a very important mechanism known as the lever. T balancing point C is the **fulcrum** (Fig. 67), and it is usual to re to one of the weights as the **force or effort** and the other as the lo

The product of any force and the horizontal distance from fulcrum to the point on the le at which the force acts is cal the **moment** of the force. If in lever shown in Fig. 66, one of weights is replaced by anot twice as heavy, it is found th the lever will only remain balan horizontally if the new weight suspended at half the distance of the first weight from the fulcru

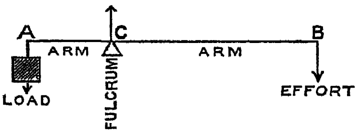


FIG. 67.—Terms used in connection with levers.

By varying the weights, it can be shown experimentally that

$$\text{Force} \times \text{distance from fulcrum} = \text{load} \times \text{distance from fulcrum}.$$

This is known as the **principle of moments.**

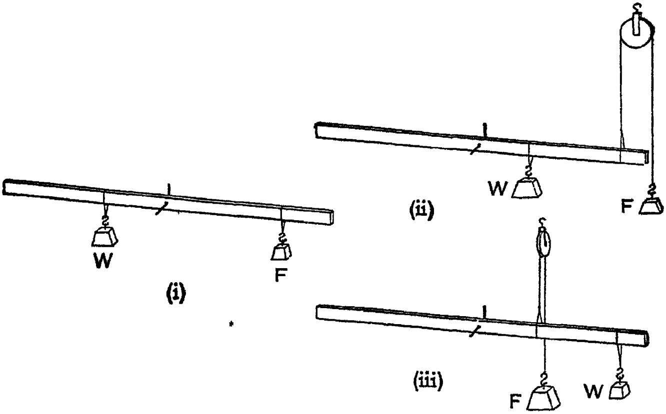


FIG. 68.—A simple lever, with the fulcrum, the load and the force arranged in three different ways.

Fig. 68 shows some different ways in which levers can be arranged. From this it can be seen that the fulcrum need not necessarily be *between* the force and the load. In every case, however, it is found that the principle of moments applies.

The ordinary balance is an example of a lever with fixed equal arms. A small lath, or a half-metre scale, hung from a point above the centre, as shown in Fig. 66, provides a means of weighing small objects. When a certain mass is hung from one side, then, by the principle of moments, an equal mass must be hung at the same distance from the centre on the other side in order to balance the lath. This fact is made use of in constructing ordinary balances or scales. The form of balance shown in Fig. 69 is similar in principle to the half-metre scale balance, described above, with small boxes hanging at equal distances from the centre. The usual household scales consist of a bar or frame-

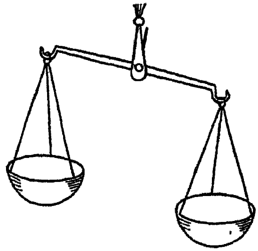


FIG. 69.—A simple balance, or pair of scales.

work supported at its centre and carrying a platform for weights at one end and a pan for the objects to be weighed at the other end.

This kind of balance is good enough for ordinary purposes, but when exact weighings are wanted, a more accurate form is used. In a balance used for scientific work (Fig. 70) the parts are very

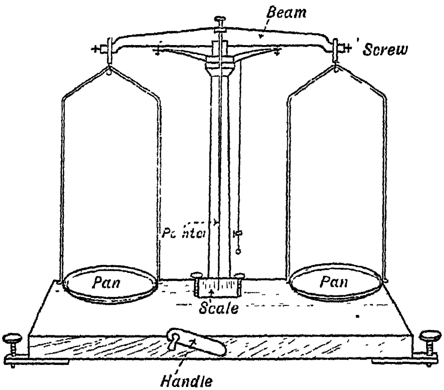


FIG. 70.—The student's balance.

carefully made, and the greatest possible pains are taken to have very delicate supports and accurate adjustments, so as to enable weights to be determined which are very small fractions of a gram.

The downward pull exerted by the earth upon equal masses, at any one place, is the same; or shortly stated, **equal masses have equal weights.** Thus any weight can be compared on a balance with the weight of standard masses. The weight of a body, which is the pull of the earth upon it, may also be measured directly by a suitably graduated spring balance.

In ordinary language, this distinction between mass and weight is not made. The word weight is used to mean both the amount of matter in a body and also the pull of the earth upon it.

The principle of work.—Work is measured by the product of a force into the distance through which a body is moved in the direction of the force. Suppose a force or effort exerted upon one arm of

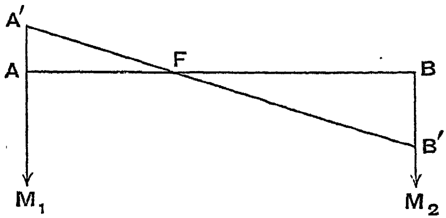


FIG. 71.—Principle of work applied to a lever.

a lever, such as M_2 in Fig. 71, moves a load equal to M_1 at the othe end through a very small distance AA', while M_2 itself moves throug BB'. It is known from geometry that the two triangles AFA' an BFB' in the diagram are similar, and therefore

$$\frac{FB}{AF}=\frac{BB'}{AA'}.$$

From the Principle of Moments,

$$M_1 \times AF = M_2 \times FB;$$

$$\therefore \frac{M_1}{M_2}=\frac{FB}{AF}.$$

But it is shown above that

$$\frac{FB}{AF}=\frac{BB'}{AA'};$$

$$\therefore \frac{M_1}{M_2}=\frac{BB'}{AA'}.$$

Thus, since the small arcs through which the effort and load mov are practically equal in length to BB' and AA', then the distanc through which the effort is exerted bears the same ratio to th distance through which the resistance is overcome that the resistanc itself bears to the effort. In other words, what is gained in forc is lost in distance.

From the principle of work it follows that if a man, by exerting force of 10 lb. on one end of a crowbar, moves 100 lb. at the othe end, he has to exert his effort through 10 inches in order to mov

the mass 1 inch. Thus, what is gained in effort has to be made up by distance moved.

Machines.—The term **machine** is applied to **any contrivance by which a force acting at a given point and in a given direction may be rendered available at some other point and in some other direction.** The lever is the simplest machine. In some machines a *small* applied force may give rise to a *greater* force acting at another point and in another direction ; in such cases, the ratio of the resulting force to the applied force is termed the **mechanical advantage** of the machine ; or

$$\text{Mechanical advantage} = \frac{\text{resistance overcome}}{\text{effort exerted}}.$$

The principle of work may be applied to all machines. That is to say, assuming there is no loss by friction, the effort used, multiplied by the distance through which it acts, is equal to the resistance multiplied by the distance through which it is overcome.

The pulley.—A pulley is a wheel having a grooved rim, and capable of rotating about an axis through its centre. The frame holding the pulley is called the **block**. With a single *fixed* pulley, no mechanical advantage is obtained. All that the pulley does is *to change the direction of the pull* (Fig. 72). For example, in hoisting a load up the outside of a warehouse, the fixed pulley at the top makes it possible to *raise* a load vertically by means of a *downward* pull on the rope or chain.

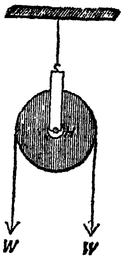


FIG. 72.—Use of a single fixed pulley.

Use of movable pulleys.—The fixed pulley is of no advantage in reducing the force required to raise a load ; but an advantage can be gained by the use of a movable pulley. In the case of the experiment (illustrated on p. 95), one-half of the load, W, is supported by the part of the string hooked to the beam, and the other half is supported by the part of the string which goes around the fixed pulley to the effort marked P. Thus any effort applied at P will support at W a weight twice as great. The movable pulley has therefore given a mechanical advantage of $\frac{2}{1} = 2$.

There are several different combinations of pulleys, but the same principle, namely, that every movable pulley reduces by one-half the effort required to support or raise the load below it, is utilised in them all. Thus in the combination shown in Fig. 73, there are three pulleys on the fixed block and three on the movable block. The load is thus supported by six cords, and, neglecting the effect of friction of the pulley wheels, the force required to raise the load is one-sixth of the weight of the load. A load of 6 lb. can thus be supported by an effort of 1 lb., and the mechanical advantage is $\frac{6}{1}=6$. By means of such pulley blocks, very heavy loads can be raised.

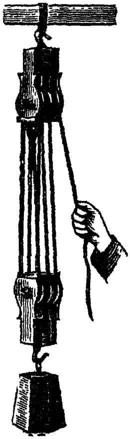


FIG. 73.—Two sets of pulleys each containing three pulleys gives a mechanical advantage of 6.

The inclined plane.—When a heavy trolley is attached to a string and allowed to rest on an inclined board as in Fig. 74, there is a decrease in tension compared with that observed when the trolley hangs freely. The reason for this will be understood by applying the principle of work (p. 88). Thus, if the trolley is moved from B to A it is lifted through a vertical height OA. For this to be done the effort, P, must be exerted over a distance BA, that is, the length along the plane. Therefore, if W is the weight of the trolley,

$$\mathrm{P} \times BA = \mathrm{W} \times OA \quad \text{or} \quad \mathrm{P} = \mathrm{W} \times \frac{OA}{BA}.$$

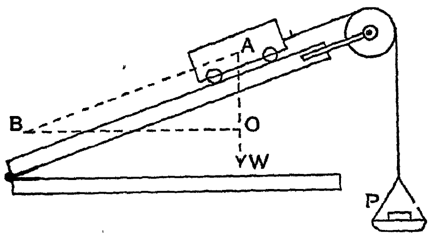
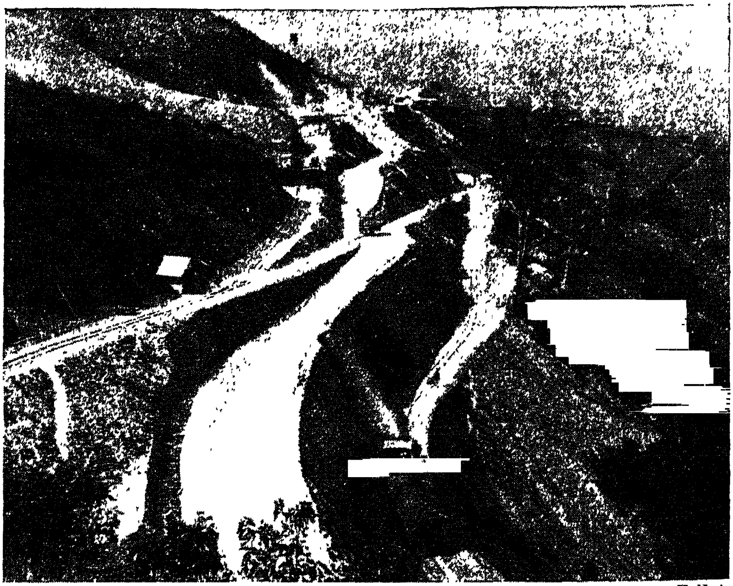


FIG. 74.—The inclined plane.



E.N.A.

FIG. 75.—A typical reversing station on the Darjeeling-Himalayan Railway. Trains ascend the mountainside by a series of gentle inclines. The engine *pulls* the train up one incline, stops, and *pushes* it up the next. A road is also shown ascending the hillside by a similar incline.

Since OA is always less than BA, then P is less than W; in other words, a heavy load can be hauled up an inclined plane by a much smaller effort, and mechanical advantage is gained. Thus a loaded handcart can be pulled up a short inclined plane placed before a step of a doorway with much less effort than would be required to lift the cart vertically up on to the step. Railways and roads ascend to great heights in mountainous regions by a series of long gentle inclines (Fig. 75).

The mechanical advantage to be obtained by the use of an inclined plane can be found from the equation obtained on p. 91, namely:

$$\text{P} \times BA = \text{W} \times OA,$$

or $$\frac{\mathrm{W}}{\mathrm{P}}=\frac{BA}{OA}.$$

Then mechanical advantage $=\frac{\mathrm{W}}{\mathrm{P}}=\frac{BA}{OA}.$

Thus the mechanical advantage of an inclined plane is given by the ratio of the slope to the height. It is greater for a small inclination than for a steep slope.

It should be noted that in actual practice the effect of friction is always apparent, so that the force required to raise a certain load is somewhat greater than that obtained by calculation.

The kite.—When a kite is stationary in the air, there are three forces acting on it in equilibrium with one another (Fig. 76). These are (*a*) air pressure acting on the undersurface of the kite, the effect being that of a force, P, perpendicular to the surface of the kite; (*b*) the weight of the kite, W, acting vertically downwards; and (*c*) the tension of the string, T. If P exactly balances W and T the kite will be stationary. An extra gust of wind will increase P; since the weight of the kite is constant, this is met by an increase in the tension, T, provided by the kite rising higher. If the wind drops, P decreases, and accordingly the kite descends. The tail acts as a brake, steadying the kite and preventing rapid movements with small variations of wind pressure.

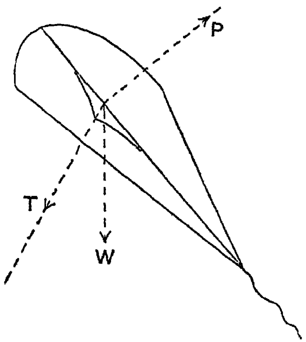


FIG. 76.—A kite when flying is acted on by three forces: air pressure P, weight of the kite W, and tension of the string T.

An aeroplane depends on a similar principle. The tension of the string is replaced by the "pull" of the propeller; the weight of the machine is constant; and the wind pressure, due to the forward motion of the aeroplane, acts on the sloping undersurface of the wings.

Springs and their uses.—Any piece of material the shape of which can be altered by the application of a force, and which afterwards

shows a strong tendency to recover its original shape, may be calle a *spring*. The form in which a spring is made depends upon th use for which it is intended. In the spring balanc (p. 79), what is known as a **helical spring** is usec Here the elasticity of the spring is utilised fc measuring weights.

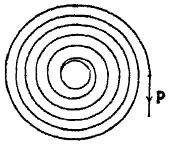


FIG. 77.—Spiral spring.

Spiral springs are used in watches and sma clocks. The energy expended in winding is store in the spring (see p. 77) ; when the watch or cloc is going, this energy is gradually used up in workin the machinery, the rate of working—that is, the rate of unwindin of the spring—being regulated by means of balance wheel or pendu lum.

Carriage springs consist of flat strips of steel of gradually increasin length, securely fastened together (Fig. 78). The spring is fastene

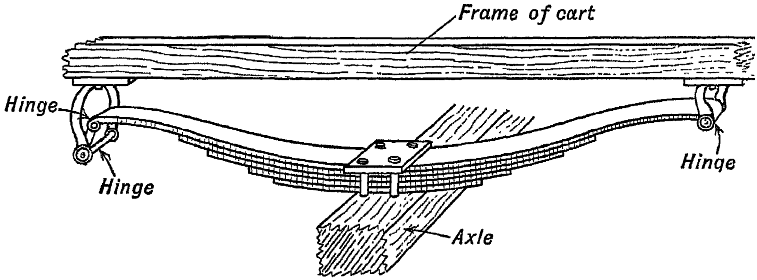


FIG. 78.—Carriage spring.

at its mid-point to the axle and the carriage itself is attached b shackles or hinges, permitting movement in a vertical plane, t the ends of the spring. The jolts which unevenness of the road or joints in a railway track would cause, are taken by the springs, which bend and recover, with little movement of the ends attached to the carriage. Thus the vibration and jolting of the carriage itself is much reduced.

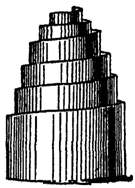


FIG. 79.—Volute sprin

Volute springs (Fig. 79) are used for lessening the effect of shocks, as in railway buffers.

PRACTICAL WORK

1. **Principle of the lever.**—Bore a hole in the centre of a long woode ruler, and hang the ruler up on a nail or a piece of thick wire. On loop of thin string hang two 1 lb. weights, one on each side of the centre Note that the rod will remain horizontal only when the weights han at equal distances from the centre. Replace one of the weights by 2 lb. weight; then for the ruler to be horizontal, this must be place at half the distance of the 1 lb. weight from the centre. Repeat th experiment with different weights and distances.

Tabulate the results as follows:

Force	Distance from fulcrum	Moment of force	Load	Distance from fulcrum	Moment of load

Compare the moments of the force and of the load. Does this verify the principle of moments?

2. **Simple pulley.**—Hang a pulley from a stand or nail, and over the wheel or sheaf pass a fine flexible cord having a loop tied at each end. Hang a light tray or bag on each end of the cord. Put a load in one of the trays, and then gradually place bits of lead or small nails in the other until the first tray moves. When this happens, take each of the trays and find the weight of each with its contents. Repeat the experiment with different loads, and record the results in parallel columns.

The trays with their loads will be found to be nearly equal. Any difference is due to the friction of the pulley upon its axle.

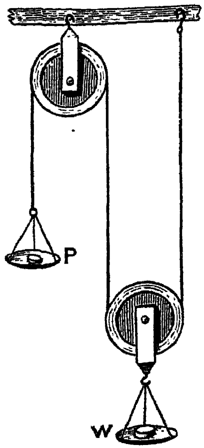


FIG. 80.—A movabl pulley and a fixed one $P=\frac{1}{2}W$.

3. **Combination of pulleys.**—Arrange one fixed and one movable pulley as in Fig. 80. Place various loads in succession in the tray **W**, suspended from the movable pulley, and add lead or shot to the tray **P** until **W** begins to move. Then disconnec the pulleys and find the weight of **P** and its contents, and the tota weights of **W** and the movable pulley.

Tabulate your observations thus :

Total load lifted (W + pulley)	Moving force, P	$\frac{\text{Total load}}{\text{Moving force}}$

4. Inclined plane.—Arrange two flat boards hinged at one end to form an inclined plane (Fig. 74). Place a trolley upon the plane and pass a string from it—and parallel to the plane—over a pulley at the top. Put different weights on the trolley, and find what weight is required in the scale-pan P just to move the trolley up the plane.

Tabulate the following results :

Load + weight of trolley (W)	Total weight at P (P)	Mechanical advantage $\left(\frac{W}{P}\right)$

Measure BA and AO. Compare the ratio $\frac{BA}{AO}$ with $\frac{W}{P}$ found above.

Repeat the experiment with the inclined plane at different slopes. Notice that the mechanical advantage is equal to the ratio of the incline to its vertical height, and that the steeper the incline the less the advantage.

CHAPTER X

GRAVITY. THE PENDULUM

Resultant of parallel forces.—If a wooden scale on which are hung two known weights is balanced on the edge of a " three cornered " file resting on a spring balance (Fig. 81), it will be found that the load

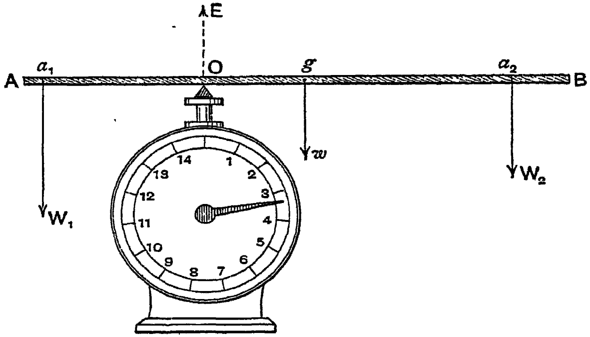


FIG. 81.—Two weights hung from a wooden scale balanced at O can be replaced by a weight equal to their sum and acting at O.

indicated by the spring balance is exactly equal to the total weight of the scale, the file and the balancing weights. Hence the weight of the balanced system could be replaced by a single force acting at the fulcrum (the edge of the file). Any system of parallel forces can similarly be replaced by a single force acting in the same direction as the parallel forces and equal in magnitude to their sum.

Centre of gravity.—Consider a stone, or any other object, suspended by a string. Every particle of the stone is being pulled

vertically downwards by the force of gravity, as indicated in Fig. 82. The resultant of these parallel forces is represented by the line GF, and the centre of the forces is the point G. The point G, through which passes the resultant (GF) of the parallel forces due to the weights of the separate particles of the stone, is known as the **centre of gravity**. For the stone to be in equilibrium, the string must be attached to a point in the line GF, produced upwards.

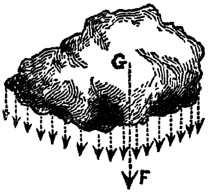


FIG. 82.—Resultant (GF) of parallel forces, showing centre of gravity (G).

Every material object has a centre of gravity, and the position of this point for a particular object is the same so long as the object retains the same form. The centre of gravity need not be, however, a point on the actual object. For example, the centre of gravity of a ring of uniform thickness is ~~at~~ the centre of the ring.

The centres of gravity of straight lines, circles, squares and other regular figures are at their geometrical centres. Hence the geometrical constructions for determining these central points also locate the position of their centres of gravity.

In the case of an unsymmetrical figure, an experimental method of determining the centre of gravity may be used. The figure is suspended so that it hangs freely, and a vertical line is drawn from the point of support. This vertical line passes through the centre of gravity. The intersection of this line with another line drawn similarly when the figure is suspended from a second point, shows the exact position of the centre of gravity (Fig. 83).

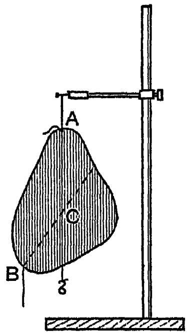


FIG. 83.—Finding the centre of gravity of a piece of cardboard.

After the centre of gravity of a sheet of metal, or other stiff material, has been determined, the sheet can be balanced horizontally on a pointed upright immediately under the centre of gravity. This is a convenient means of checking the correctness of the experiment performed.

Equilibrium.—When a body is at rest, all the forces acting upon it balance one another (or, what is the same thing, any force is equal and opposite to the resultant of the remaining forces) and it is said to be in equilibrium.

A long stick or cane can be swung about if held loosely between the finger and thumb, and will always come to rest hanging vertically downwards. Its centre of gravity (*G*) is about half-way along its length, and swinging movement will *raise* it to *G′*; the stick is said to be in *stable* equilibrium (Fig. 84). The stick can also be balanced standing on the end of one finger (Fig. 85), but the slightest movement will *lower* the centre of gravity and the stick will topple

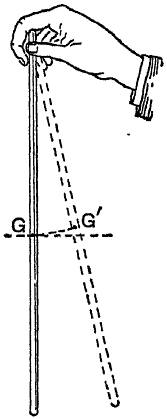


FIG. 84.—Stable equilibrium.

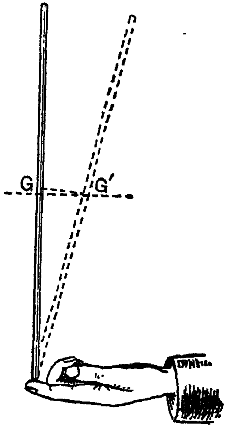


FIG. 85.—Unstable equilibrium.

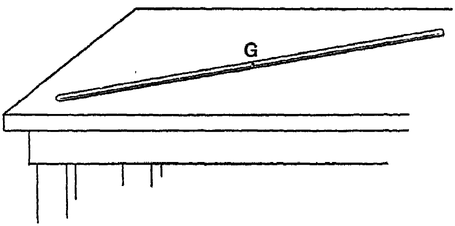


FIG. 86. —Neutral equilibrium.

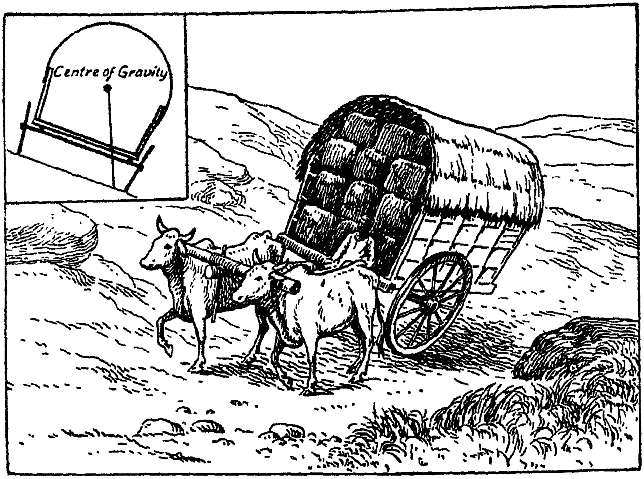


FIG. 87.—If the vertical line from the centre of gravity should fall outside the base of support, the cart would topple over.

over; it is said to be in *unstable* equilibrium. If the stick is laid horizontally on a table, then it can be rolled about without raising or lowering the centre of gravity; it is in *neutral* equilibrium, and remains wherever it is placed (Fig. 86). Thus, if the centre of gravity is raised by a small movement, the object is in stable equilibrium; if it is lowered, there is unstable equilibrium; if it is unaffected, there is neutral equilibrium.

Relation of centre of gravity to base of support.—A circular disc, in which the centre of gravity coincides with the geometrical centre, will not rest upon a table if the centre is beyond the edge of the table, but will topple over. In a similar way, if any plane figure lies flat upon a table, the centre of gravity of the figure must be within the edge of the table. The same conditions apply to any object resting upon a support. For an object resting upon a base to be in equilibrium, a vertical line drawn from the centre of gravity downwards must fall within the base. When this vertical line falls outside the base, the body topples over.

Consider the case of a cart or carriage on level ground. The

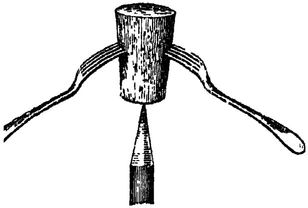


FIG. 88.—With the aid of two forks a cork can be balanced on a point, because now the centre of gravity is *below* the point.

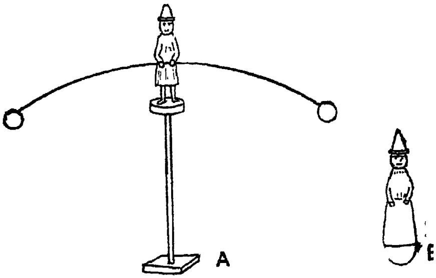


FIG. 89.—Balancing toys.

centre of gravity is somewhere inside the vehicle, and a vertical line drawn from it downwards would fall within a line traced around the vehicle upon the ground. But if the vehicle is loaded so as to be top-heavy, and it happens to be running across a sloping road, it might topple over, for a jerk would cause so great a change of position of the centre of gravity as to make the vertical line from the centre fall outside the base of support, and in such a case an accident would happen (Fig. 87).

When a rope-walker goes through his performance he bears in his hands a long rod heavily weighted at each end. This he carries as low down as possible, thereby bringing the centre of gravity of himself and the rod towards the lower part of his body; it also enables him easily to alter the position of the centre of gravity by a small amount towards one side or the other as may be necessary to preserve his balance. Some tight-rope walkers dispense with the weighted rod and balance themselves by swaying their arms and by bending the body to one side or the other.

It is very difficult to balance a cork on a pencil point, but if two forks are stuck into the cork, as shown in Fig. 88, the matter becomes easy, since the centre of gravity of the whole is actually lower than the point of support, and stable equilibrium is now attained.

This principle is made use of in both the toys illustrated in Fig. 89. In *A*, the figure is made of light material and the balancing wire carries two heavy metal balls. In *B*, the figure is made of cardboard or similar material and the hemispherical base is of

E.N.A.

FIG. 90.—A canoe with an outrigger has a wide " base of support ", and is not easily capsized.

metal. In both cases the centre of gravity is vertically within the base and close to the point of support, so that both of them return to the position of equilibrium if displaced. A hydrometer (see p. 5) stands upright in water for a similar reason to that of the toy *B*, because it has at its base heavy mercury which serves the same purpose as the lead in the toy.

Similar principles apply in the case of a ship afloat. If the ship is carrying cargo, the weight of this is as a rule enough to keep the centre of gravity low, so that the ship is stable in the water. The buffeting of the waves makes the ship roll, or rock, first to one side and then to the other, but the centre of gravity being down near the bottom of the ship, the ship rolls back to the upright position after each blow. **Ballast** such as heavy iron bars or stones,

must be placed in the hold of a ship having no cargo, in order to keep the centre of gravity low, as when the ship is carrying cargo; otherwise it is in danger of capsizing—that is, it would be unable to swing upright again after being rolled to one side by the waves.

Native boats are prevented from capsizing under the pressure of wind on the sails by an outrigger (Fig. 90); in this case the centre of gravity is high but the "base of support", namely the boat and outrigger, is wide, so the centre of gravity is kept within it when the boat heels over.

The pendulum.—A simple pendulum may be made by attaching a heavy weight to a thin piece of string, the weight of which may be neglected in comparison with the weight of the bob (Fig. 91). The time taken by a pendulum to make a *complete* vibration to and fro—that is, the time it takes to travel from its lowest position first to one side, then through the lowest position to the other side, and back again to the lowest position—is known as its **period**, or **time of vibration.** The distance from one extreme position of the swing to the other is called the **amplitude** (Fig. 91, *AB*).

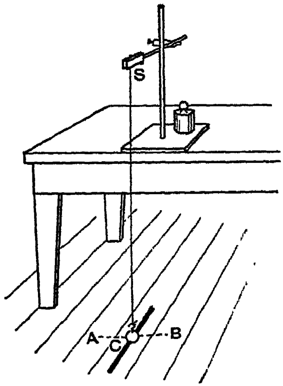


FIG. 91.—A simple pendulum.

Experiment shows that the time for each vibration is not altered when the weight of the bob is altered if the length of the pendulum remains the same; that the amplitude of the vibration has no effect on the time for each vibration, so that all pendulums of the same length will have the same time of vibration—that is, they are *isochronous*; but that a variation in the length of a pendulum does alter the time.

A pendulum of a fixed length has a constant rate of vibration. Observations show that a pendulum 39·055 inches long from the point of suspension to the centre of the bob, if set swinging in the latitude of Dehra Dun, completes one swing from left to right in a

second of time (that is, its period is 2 seconds). The place must be specified because the rate at which a pendulum swings differs slightly in different latitudes owing to the facts that the earth is not a perfect sphere and that it is in rotation.

This fact of the constancy of vibration is utilised in the construction of many clocks, in which the pendulum consists of a light rod with a heavy bob. In other clocks, and in watches, an oscillating balance wheel is used instead of a pendulum. In both clocks and watches, the hands are forced round the face by a system of cogged wheels which are geared to each other. The wheels themselves are set in motion by the unwinding of the mainspring, or by a chain to which is attached a weight, previously raised, and falling gradually. The rate at which the weight falls is controlled by the pendulum. At each end of the swing the weight or spring is released by a contrivance called the *escapement*, and so the hands are pushed forward through a constant distance for each swing of the pendulum. The balance wheel of a watch acts in a similar way. Since heat causes a pendulum to expand, special devices are used so that the *effective* length of the pendulum is unaffected by change of temperature (see p. 45).

Pendulum length and period.—In order to find the relation between the length of a pendulum and the time of vibration, several experiments are made with pendulums of different lengths, and the times they take to perform, say, twenty complete vibrations are recorded. In this way it is found that as the length of the pendulum is increased, the time of vibration also increases, but the two do not increase together in a simple way. If, however, the length be compared with the *square* of the time of vibration, then it is seen that these quantities increase in proportion—that is, if the length is doubled, the square of the time of vibration is also doubled, and so on.

Hence the length of a pendulum is proportional to the square of its time of vibration ; or, **time of vibration is proportional to the square root of the length.** Using symbols, if t is time of vibration, l is length of pendulum, and k is a constant, then for any pendulum,

$$t = k\sqrt{l}.$$

PRACTICAL WORK

1. **Parallel forces.**—Weigh a wooden rod or ruler, and mark its middle point (g). On it hang two known weights at a_1 and a_2, and support the rod on the edge of a "three-cornered" file standing on a balance as in Fig. 81. Shift the rod until the point O is in such a position that the whole is in equilibrium. The sum of the forces $\mathbf{w}$, $\mathbf{W}_1$ and $\mathbf{W}_2$ should now be equal to that indicated by the balance. Thus one force acting downwards at O would have the same effect as the three forces acting at different points.

2. **Centre of gravity of a piece of cardboard.**—(*a*) Obtain a piece of cardboard or other stiff material of uniform thickness. Attach a cord near the edge and suspend the cardboard from a stand, as indicated in Fig. 83. Hang a plumb-line from the same hook. Draw a vertical line on the cardboard under the plumb-line. Suspend the cardboard in another position by means of a second thread. Draw another vertical line upon it. The point of intersection of the two lines marks the *centre of gravity*. Test the result by seeing whether the cardboard will balance at this point.

Repeat the experiment with sheets of different shapes.

(*b*) Place one of the pieces of cardboard previously used near the edge of a square-edged table, and push it gently until it would just topple over if permitted. When this condition is obtained, mark upon the underside of the card where the edge of the table comes. Repeat the experiment with the cardboard in a different position, and again draw a line on the underside. Test whether the point of intersection of these lines marks the centre of gravity.

3. **The simple pendulum.**—Attach to one end of a piece of thread about a metre long a leaden ball about 25 mm. in diameter ; fasten the other end of the thread to a clamp of a retort-stand. Place the stand on the bench and allow the ball to hang over the edge (Fig. 91). The length of the pendulum is the distance from the point of support to the centre of the ball, and is determined by measuring the length of the thread as it hangs and adding half the diameter of the ball. When the ball is pulled to one side and allowed to swing—it must not be *pushed*—the ball swings from side to side, or *vibrates* ; and the *time*, or *period*, of *vibration* is the time between two successive passages of the ball *in the same direction* through the lowest point.

4. **Time of vibrations.**—(*a*) To measure the time of vibration, mark a chalk line on the floor below the bob when it is at rest. Draw the bob to one side, and allow it to go *from left to right*. On a watch with a seconds hand note the time when the bob crosses the chalk line and count 0 ; when the bob crosses the line again *from left to right* count 1 ;

and so on up to 20, when the time is again noted. This gives the time for 20 vibrations. Use the same bob but alter the length of thread and again determine the time for 20 vibrations. Repeat this using pendulums of different lengths.

Tabulate your results thus :

Length	Period	$(\text{Period})^2$	$\frac{\text{Length}}{\text{Period}}$	$\frac{\text{Length}}{(\text{Period})^2}$

It will be found that the ratio of the length to the square of the period is always the same; hence the period is proportional to the square of the length of the pendulum.

(*b*) Repeat the previous experiment but this time keep the length of the pendulum the same, and alter the weight of the bob by using balls of different weights.

(*c*) Use a pendulum having the same length and the same bob, but alter the amplitude of the vibration by pulling the bob farther from the vertical position in each experiment. The time required for 20 vibrations should be noted in each case.

(*d*) Vary the length of the string until the pendulum makes thirty swings—that is, half-vibrations—in half a minute; that is, it beats seconds. Measure the distance from the point of suspension to the centre of the weight; it will be found to be about 39·2 inches.

CHAPTER XI

ENERGY AND HEAT

A simple steam engine.—The steam engine and boiler may be looked upon as contrivances for converting into *mechanical work* the energy contained in the coal or other fuel in the form of potential *heat*. Steam is generated from water by the application of heat. When an open vessel is used, the steam is given off at the same pressure as that of the atmosphere, but a much higher pressure may be secured by generating steam in a closed vessel. Steam may be used for the production of work by allowing it to push a piston to and fro in a cylinder; or, by causing it to discharge against vanes fixed around the circumference of a wheel, thus producing rotation. The action and arrangement of the parts of a small engine of the first-mentioned type will here be described.

Steam engines having pistons working in cylinders are generally employed to give a motion of rotation to a shaft. An outline diagram of the mechanism is given in Fig. 92. The motion of the

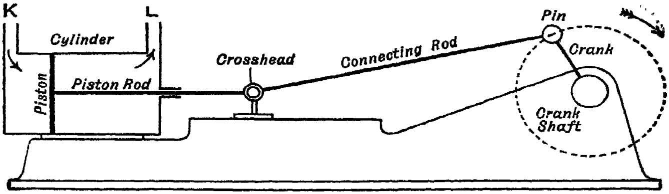


FIG. 92.—Outline diagram of steam-engine mechanism

piston is communicated to the shaft by a **piston rod** and a **connecting rod** and a **crank**. The piston slides in the cylinder and is fitted so as to prevent leakage of steam past its edges. A piston rod is attached to the piston and passes through one end of the cylinder, the

ole being made steam-tight. The outer end of the piston rod is)inted by means of a pin to one end of the connecting rod; this)int is called the **crosshead.** The other end of the connecting rod ; attached to a pin secured to the crank, which is mounted on a **·ank shaft.** As the piston moves to and fro in a straight line, the in follows the circumference of a circle and the shaft rotates.

Steam is admitted to the cylinder first through the opening or)rt K, and it exerts pressure on the left-hand side of the piston, he other side being put into communication, through the port L, ith the atmosphere, or with a vessel called a **condenser,** in which he pressure is kept low. The steam, by its pressure, causes the iston to travel to the right-hand end of the cylinder. The admis-ion of steam to the cylinder is controlled by a valve, which is)ined by a rod to a ring which slides round an *eccentric* disc fixed n the shaft. The disc being eccentric—that is, out of centre—the lide valve moves to and fro as the shaft revolves.. The crank shaft ; made to execute half a revolution. Steam is then directed into he right-hand side of the cylinder through L, the left-hand portion eing put into communication with the atmosphere or with the ondenser through K, and the piston is thus driven back to the eft-hand end of the cylinder, the crank shaft meanwhile completing he revolution. To enable the crank shaft to rotate smoothly with-ut jerky action, a heavy wheel called a **fly-wheel** may be attached o it.

The fly-wheel operates by storing a large quantity of energy in he kinetic form while the engine is getting up speed. It is then ble to meet any deficiency which might be caused by a sudden lemand for more energy, by giving up some energy from its store. This it is able to do by changing its speed to a comparatively small xtent.

Valves are designed generally so as to admit steam to the cylinder nly during the early part of the stroke and then to cut off the upply, the remaining part of the stroke being accomplished by the *xpansive action* of the steam, giving a continually diminishing pres-

The engine is kept at a required steady speed by means of a device called a **governor**, which in the steam engine regulates the supply of steam to the cylinder. The governor usually consists of two heavy balls connected by arms with a sleeve which slides on a spindle, and by so doing causes a **throttle valve** placed in the steam pipe to open or close. The sleeve is normally held in position by a spring so that, when the engine is stationary, the throttle valve is fully open. When the engine is running and driving the governor spindle, the balls are swung outwards until a steady position is reached, which depends on the speed of rotation. Any increase in the speed will cause further outward movement of the balls, producing an upward movement of the sleeve, and this, being transmitted to the throttle valve placed in the steam pipe, will close it partially, and so reduce the supply of steam to the engine; the engine speed will thus fall. Should the speed be lowered below the proper amount, the balls move inward, thus lowering the sleeve, with the result that the throttle valve is opened more, and therefore more steam is permitted to pass to the engine.

Internal combustion engines.—All engines in which the fuel undergoes combustion *inside the engine cylinder* and not in a separate furnace as in the steam engine, are called *internal combustion engines*. The general arrangement of the cylinder and piston is almost the same as in the steam engine, but whereas in the latter the movement of the piston is caused by the force of expanding steam, in the internal combustion engine the same effect is obtained by the explosive force of burning gases. The fuel used is either gaseous—coal-gas is often used—or a liquid which is readily vaporised. Suitable liquids are *petrol, benzene* and *alcohol*. Any of these, when vaporised, forms an explosive mixture with air.

Fig. 93 is a diagram of a gas engine. Comparing this with Fig. 92, it is seen that there is no piston rod, the piston (*B*) being connected directly with the connecting rod (*D*). The end of the cylinder at *A* is open, and the piston is consequently exposed to the atmospheric pressure at this end. The charge, consisting of about one part of gas to eight parts of air, is sucked through a valve into the left-hand end of the cylinder by an outward movement of the

piston. As the fly-wheel continues to turn, the cylinder fills with the charge and the piston begins to return. The inlet valve closes, so the charge is compressed. When the piston has again reached the left-hand end of the cylinder, the charge is much compressed, and then it is exploded either by a hot tube connected with the cylinder, or, more commonly, by an electric spark. *F* is a water-jacket surrounding the cylinder. Cold water circulating in this keeps the temperature from rising too high. The force of the explosion drives the piston to the right. As the revolving fly-wheel causes the piston to move back into the cylinder, the spent gases are forced out through the exhaust valve (*E*), which is connected by a crank with the fly-wheel. Thus there are two revolutions of the

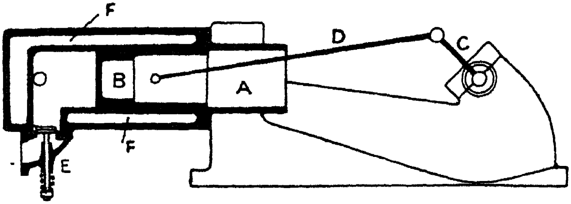


FIG. 93.—Outline diagram of a gas engine.

fly-wheel and four strokes, two forward and two backward, of the piston for each charge fired in the cylinder, and such an engine is said to work on a **four-stroke cycle.**

Motor cars and aeroplanes are generally driven by engines of this type including two, four, six, eight and, in the case of the aeroplane, even larger numbers of cylinders. The fuel used is petrol; this is vaporised in a carburettor by forcing it through a fine jet, and the vapour mixed with air passes into the cylinder, where it is fired by an electric spark. Where there are two or more cylinders, matters are so arranged that they are fired in turn. As a result, the fly-wheel receives a series of impulses during each revolution instead of one impulse in two revolutions, and the movement is therefore steadier.

In heavy motor vehicles such as motor omnibuses and lorries, and also in large motor vessels and in modern Zeppelins, a form of internal combustion engine known as a **Diesel** engine is fitted. This

is similar to the petrol engine except that the fuel used is a heavy oil, which is forced into the cylinders as a very fine spray and, as it is compressed, becomes so hot that it ignites and explodes, driving the piston forward as in the petrol engine. There is less danger of fire with such engines, because the oil used as fuel is not so inflammable as petrol.

Gears.—When an engine is used for working machinery, it is often necessary to transmit power from one shaft to another. If there is a considerable distance between the shafts, this is usually done by means of a wheel and belt. If it is required that the *driven* shaft should rotate at a greater speed than the *driving* shaft, the wheel on the former is made smaller than that on the latter, and *vice versa*. For example, if the driven shaft is to rotate at twice the speed of the driving shaft, the diameter of the wheel should be half that of the driving wheel.

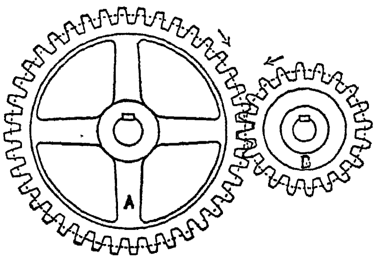


FIG. 94.—Toothed wheels in gear.

When the shafts are close together, *toothed wheels* may be used, and are placed in contact. In this case the wheels rotate in opposite directions. Obviously the size of the teeth on both wheels must be the same, and the number of teeth is proportional to the diameter. The speed of rotation is inversely proportional to the number of teeth.

A bicycle is geared by means of two toothed wheels and a chain (Fig. 95). If the number of teeth on the *crank chain wheel* (A) is 40, and the number on the *sprocket wheel* (B) is 20, then for one revolution of the pedals the back wheel moves through $\frac{40}{20}=2$ revolutions.

Heat from mechanical work.—In the case of the steam engine, heat is converted into mechanical work; conversely, mechanical work can be converted into heat. When a brake is applied to the wheels of a train as it stops at a station, it is a common thing to see sparks fly. The resistance of friction which overcomes the motion

of the train causes a sufficient amount of heat to be developed t(raise the temperature of the particles of steel, which get rubbed off to a red heat.

Many other examples of the production of heat from mechanica work may be seen in everyday life. Thus, by continually hammerin; a piece of iron on an anvil it can be made too hot to hold in the hand When a lucifer match is rubbed along a rough surface, the heat int(which the work is converted is enough to ignite the match. Primi

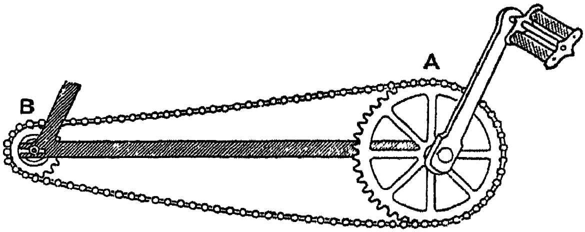


FIG. 95.—The crank and sprocket wheels of a bicycle. The "gear" of a direct-drive bicycle depends upon the relative number of teeth on the crank wheel and the sprocket wheel.

tive tribes still obtain fire by twirling a piece of pointed hardene(wood in a hollow in another piece of wood (see p. 284). The frictio produced is converted into heat which ignites some shavings place(in the hollow. When a wheel turning on an axle is not properl lubricated, it becomes hot, because the work done in turning th wheel round becomes heat; the heating may easily become so grea that the axle expands and grips the wheel tightly. For this reasor the axle boxes of railway coaches are examined at frequent interval on a long journey.

Energy and heat.—Since heat may, by suitable means, be con verted into mechanical work, and work is expended in prc ducing heat, the question arises: How much heat can be develope(by the expenditure of a given quantity of work? Or putting th question in another way: How much work can be produced by th complete conversion of a given quantity of heat into work? Th answer to these inquiries has been obtained by very precise experi ments; and the quantity of mechanical work which corresponds t

a unit quantity of heat is termed the **mechanical equivalent of heat.** The results of a large number of experiments show that to **raise the temperature of one pound of water through 1° F. requires an expenditure of 778 foot-pounds of work.** To raise the temperature of one pound of water through 1° C. requires 1400 foot-pounds of work.

Conservation of energy.—The establishment of the fact that heat and mechanical work are exactly equivalent to one another leads to the principle of the **conservation of energy.** One form may be changed into another, but new energy cannot be created. Thus, the energy of moving bodies, *kinetic energy*, can give rise to sound and heat; heat can be changed into the energy of moving bodies, electric currents, chemical action, and so on. It may be impossible to trace and account for some of it in the numerous transformations which it undergoes; but it is certain that if the methods of experiment were only accurate enough, it would be possible to account for the whole amount.

Consider the case of an engine which is supplied with energy from the store of *potential energy* in the fuel. The object of the engine is to convert this potential energy into mechanical work. If the engine were perfect, it could convert a large part of this energy into work. But actual engines are by no means perfect; the ordinary steam engine can only convert a small fraction of the available energy into work, while the efficiency of an internal combustion engine is about twice that of the steam engine. The ratio of the work done by an engine to the available store of energy is known as the **efficiency of an engine.** Part of the energy of the fuel is dissipated in warming the parts of the mechanism, part in heating and expanding the products of combustion, another fraction in overcoming friction, and so on. But the sum of all these amounts, and others we have not mentioned, together with the work done by the engine, is exactly equal to the potential energy of the fuel.

Stores of energy.—A weight raised above the surface of the earth against the attraction of gravitation possesses a store of potential energy. When a clock driven by weights is wound up, the wheels are kept in motion for a certain time by the potential energy thus given to the weights. Watches work by gradually converting the

stored-up energy in their springs into kinetic energy of their moving parts.

Combustion is another means of transforming potential into kinetic energy. Wood and coal contain a store of potential energy which is a measure of the amount of work done by the plant in building up the chemical compounds of which it is composed. Similarly, articles of food are reservoirs of potential energy. Living animals are continually using up this energy in performing the various functions which attend their life.

It is interesting to note that the vegetable kingdom serves the purpose of changing the energy of the sun's rays into the potential energy of both fuel and food. This has been seen in sufficient detail in the case of fuel; and since all animals are dependent either directly or indirectly (through the agency of other animals) upon plant life for their food, it is clear that it is equally true of the food which we and other creatures eat.

Water above sea-level possesses a store of energy; and it owes this potential energy to the sun's activity. The sun causes rain by bringing about evaporation from the water on the earth's surface and the energy of the sun's rays is largely consumed in raising this water to a higher level, in which position, as in the case of the raised weight already considered, it is so situated that it can, under suitable conditions, give out its store of energy in a kinetic form.

Another available source of potential energy is tidal water-power. If part of the water of the sea or a tidal river is entrapped by a dam or barrage when the tide is high, the potential energy of the water prevented from retreating can be utilised after the tide has ebbed. Tidal energy is chiefly due to the attraction of the moon; but, with this exception, nearly all the energy available is derived either directly or indirectly from the sun.

PRACTICAL WORK

Change of motion into heat.—(*a*) Hammer a piece of lead or saw wood, and test the temperature of the lead or saw before and after the experiment.

(*b*) Rub a metal nail or button on a wooden seat, and notice its increase of temperature.

(*c*) Compress air into a bicycle tyre or cylinder by means of a bicycle pump. Notice that the part of the pump connected with the tyre or cylinder becomes warm.

CHAPTER XII

PROPAGATION OF SOUND THROUGH AIR

Sound produced by vibration.—If a piece of string or catgut about 30 cm. long is stretched tightly between two nails driven into a board (Fig. 96) and then plucked at about its middle by the finger, a deep humming sound will be heard. So long as the sound can be heard, it will be seen that the string is vibrating very rapidly.

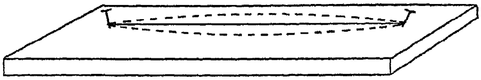


FIG. 96.—A string stretched between two nails in a board vibrates and gives a musical note.

All sounds are produced by the vibration of a material body, though such vibrations are as a rule less simple than those of a string. Slow vibrations do not give rise to audible sound, but as the vibrations become rapid, musical notes, which become shriller or of higher pitch as the rapidity of the vibrations increases, are given out. As the number of vibrations per second increases, what is called the **pitch** of the note increases. A **musical note** is heard when the vibrations fall upon the ear with regular frequency, but mixed or irregular vibrations produce a **noise**.

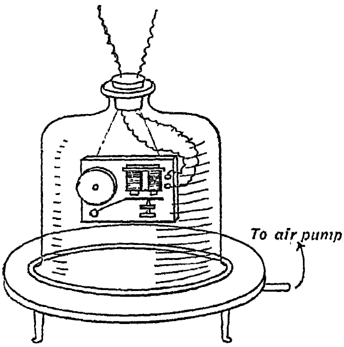


FIG. 97.—Experiment to show that sound is transmitted by air.

Transmission of sound.—An electric bell is suspended inside a bell-jar as in Fig. 97, and the air is pumped out whilst the bell is

ringing. The sound becomes fainter and fainter. It never quite dies away, since some of it is transmitted by the suspending wires. The result, however, shows that some air or other material substance is needed for the transmission of sound.

Sound is also carried through solids, and the earth itself affords a good example of this. It is common knowledge that, if the ear is put to the earth, the sound of horses' hoofs or of human footsteps can be heard at a much greater distance than through the air. That sound is transmitted by liquids is known by the fact that divers under water can hear words spoken on the bank. Sound travels through both earth and water at a greater speed than through air.

How air transmits sound.—The experiment with a stretched string shows that sound is produced by vibration of the sounding body. The air-pump experiment shows that sound does not pass through a vacuum or space devoid of air. Sound travels by means of wave-motion in air, or some other material medium, through which the sound passes. Sound-waves resemble in some respects the waves produced by dropping a stone into a pool of water. Circular waves are then seen, which travel outwards in ever-widening rings. The outward motion is confined to the *waves*. The actual particles of water receive only an up-and-down motion. This may be proved by dropping a stone near a floating piece of wood, which, although it moves up and down when the wave reaches it, is left in its original

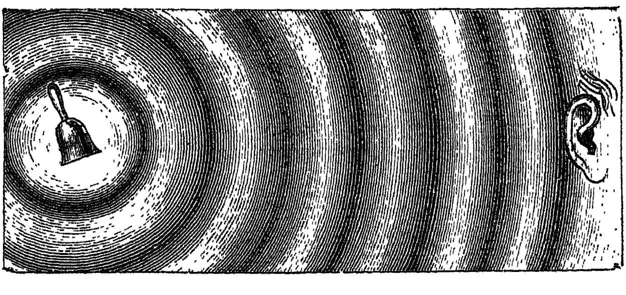


FIG. 98.—Drawing showing the passage of sound-waves through air, similar to the waves produced by dropping a stone into a pool of water.

position after the wave has passed by, unless it is acted upon by some other force. When a tuning-fork or other body vibrates in air a somewhat similar state of affairs results. The movement of the prong causes a series of waves in the air. Since the fork is surrounded by air on all sides, the waves are not confined to one plane as in the case of water, but consist of a series of spherical waves surrounding the fork or other source of vibration.

The manner in which sound-waves are produced may be illustrated by means of the following experiment:

A row of marbles is placed in a groove (Fig. 99). If another marble is rolled along the groove, when it strikes the end marble, A,

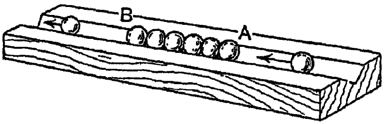


FIG. 99.—Demonstration of compression wave.

of the row it causes it to be momentarily compressed. When the end marble recovers its shape it compresses the second marble, and so on. Thus a wave of compression passes along the row until finally the marble at the further end, B, of the row is pushed away. When a tuning-fork is vibrating it acts on the air particles in the same way as the moving marble acts on those standing still. This is illustrated in the top line of Fig. 100, where a movement of the prong to the right causes a wave of compression to pass along the air particles which are represented by the lines. This wave travels along the particles as seen in the succeeding rows. A movement to the left has the opposite effect and causes a wave of rarefaction to follow in the same direction. Thus there are continuous waves of compression and rarefaction following one another as long as the prongs are vibrating rapidly. Such waves exactly correspond to those formed in an organ pipe, but it

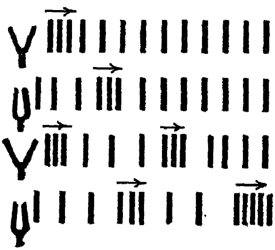


FIG. 100.—Longitudinal wave.

must be remembered that when a sound is produced in the open it travels in all directions. When such vibrations reach the ear they cause corresponding vibrations in the drum of the ear and the sensation of sound is produced.

The voice.—The sound of the human voice is produced by the vibration of membranes, which are known as the **vocal chords**, at the back of the throat. If a tube of wood is cut to a wedge shape at one end, and two rubber membranes stretched across it, as in Fig. 101,

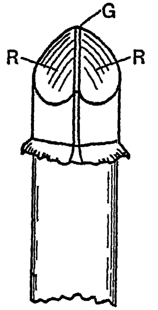


Fig. 101.—Artificial larynx. *R, R,* rubber membrane.

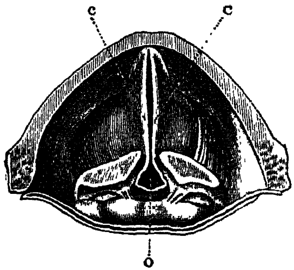


Fig. 102.—Vocal passages seen from above. *c, c,* vocal chords; *o,* glottis.

an artificial **larynx** is formed, which resembles fairly closely the human larynx or voice-producing organ. Air passing through the pipe and escaping through the narrow slit *G* or **glottis** causes rapid vibration of the membranes, the slit opens and closes, and sounds are produced.

In Fig. 102 is shown the human vocal passage as seen from above. The membranes or vocal chords are stretched across the **trachea** or **wind pipe**, and their length and tension can be altered very rapidly, giving great range of tone or **compass** to the voice. A tightening of the membranes makes the vibrations more rapid and so raises the pitch, whilst a slackening of the membranes gives slower vibrations and a deeper note. The quality of the tones is varied by altering the shape of the air chamber formed by the inside of the mouth.

The ear.—The ear is a receiving instrument by which sounds are collected, and their effects transmitted to the brain. Sound is col-

lected by the **external ear** (E, Fig. 103) and travels along the passage (M) to the **tympanic membrane** (T), which is often called the *drum* of the ear. This membrane is set in vibration by any sounds which reach it, and such vibrations are transmitted by three small bones (m, i and s) to a smaller membrane marked O in the figure. This smaller membrane forms part of the outer wall of the **inner ear**, which consists of a series of canals called the **labyrinth**. Into these canals penetrate the ends of the **auditory nerve** (A), by means of which the sensation of hearing is carried to the brain. The **middle ear** (R) is connected by a tube (Eu) to the throat, and this arrangement ensures an equal atmospheric pressure on both sides of the tympanic membrane.

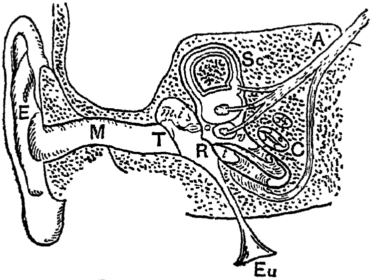


FIG. 103.—The ear.

Reflection of sound waves.—The following experiment illustrates the reflection of sound-waves. A and B (Fig. 104) are two tubes made of tin-plate or cardboard, about 1 yard long and 3 inches diameter. They are laid on a bench or table in the positions shown in the figure. A watch is suspended at E near to the end of one tube, and the ear is placed at F near the end of the other tube. If the sound can be heard, a screen, such as a wet towel, is hung at D, so as to prevent the sound-waves from passing directly from E to F. A flat board or sheet of cardboard is now placed at C in a vertical position so as to act as a reflector ;

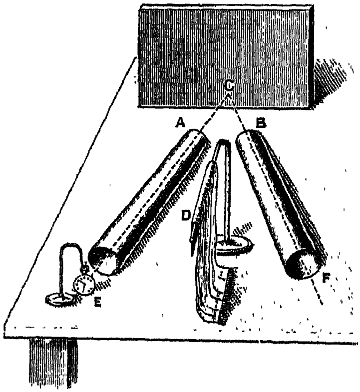


FIG. 104.—Experiment on the reflection of sound.

this is slowly rotated round a vertical axis until the sound can be heard. This position should be marked. If now a line *CD* is drawn from *C* at right angles to the position of the reflector, it should be found that the angle *ACD* is equal to the angle *BCD*—that is, **the angle of incidence is equal to the angle of reflection**, waves passing from the source of sound to the reflector being known as **incident** waves.

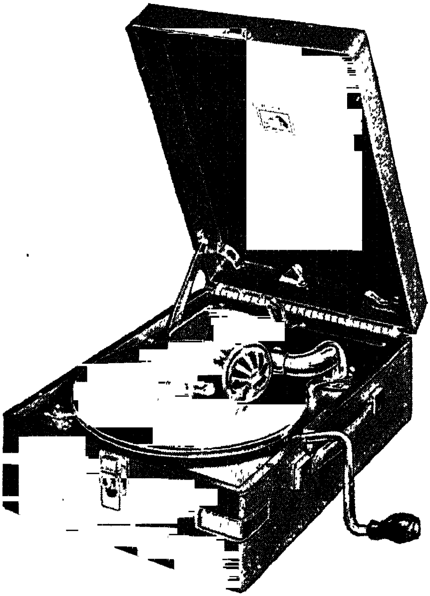
Echoes are familiar examples of the reflection of sound, and they may often be observed in the neighbourhood of large houses, high walls, cliffs or hillsides, and also in very large rooms or halls. If the sound be produced near the observer, the reflecting surface must be at a considerable distance—at least 55 feet—otherwise the echo is confused with the original sound, owing to the fact that the impression on the ear of a sound-wave persists for at least $\frac{1}{10}$ of a second. The reflecting surface must be therefore at such a distance that the sound-wave will require at least this interval of time to travel to the surface and back again.

Whispering galleries.—When the wall of a building forms a continuous curve, sound-waves are reflected just as they are from a "sound-mirror". If a person stands under the arch of a bridge, near to, and facing, one of the piers, any words which he speaks can be heard at the corresponding position beneath the other pier although inaudible in the intermediate space.

The whispering gallery in St. Paul's Cathedral, London, is famous throughout the world, and the curious effects there observed have been explained as being due to the reflection of the sound-waves so that they form a narrow belt skirting the wall, the intensity being a maximum near the wall. The intensity of sound to an observer moving in a circle parallel to the wall of the gallery varies, there being alternate zones of great intensity and almost complete silence. Inside the great dome of Gol Gumbaz, Bijapur, similar effects are heard, the echo being strongest at the opposite point from the source of sound.

The gramophone.—Sounds are produced by the vibrations of such things as a tuning-fork or the vocal chords. These vibrations are reproduced when the sound-waves to which they give rise reach a membrane such as the drum or membrane of the ear, and sounds

are heard when the vibrations are transmitted to the brain. It would seem possible, if an artificial ear or membrane were constructed, to which a pencil or other indicator could be attached, that a graphical record of sound could be obtained from the movements of the indicator. The gramophone (Fig. 105) is devised on this prin-



By courtesy of "His Master's Voice"

FIG. 105.—A gramophone, showing the sound-box and the record.

ciple. Here a mica sheet is the membrane, and by its means vibrations are transmitted through a lever to the needle. This, pressing gently against a rotating wax disc, produces wavy lines corresponding to the sounds. From this wax disc identical copies are made in a hard resinous material, and the resulting discs are the familiar " records " sold in gramophone shops. The record is placed on the rotating platform of a gramophone, and as it rotates

the needle of the reproducer is forced to follow the course of the producing needle, vibrating from side to side. It communicates its vibrations to a mica diaphragm in a sound-box (Fig. 106), and the original sounds are reproduced.

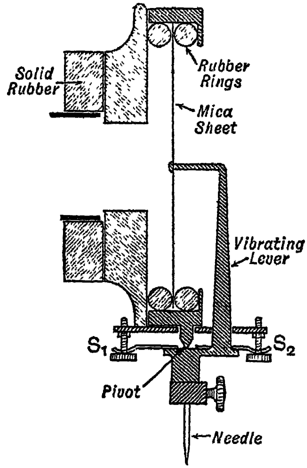


FIG. 106.—The sound-box of a gramophone. The needle traces out, from side to side, the wave-form impressed on the "record" and causes a to-and-fro motion of the mica sheet, which reproduces the sounds originally recorded.

PRACTICAL WORK

1. **Vibrating strings.**—Stretch a string or a piece of catgut tightly between two long nails driven into a long board or table. Hold the stretched string between the first finger and thumb, give it a sharp pull, and then let it go. The string gives out a distinct musical note, and careful watching shows that the string is moving backwards and forwards or *vibrating* rapidly. Although the vibrations take place too quickly for them to be seen distinctly, the string loses its clear outline owing to the rapid motion from side to side.

2. **Tuning-fork.**—Strike the prong of a tuning-fork against any hard object; it also gives out a musical note, and although it is difficult in this case to see the vibrations, if the prong is held against a thin piece of metal, or against the teeth, it becomes apparent that vibration is taking place.

CHAPTER XIII

LIGHT. TRANSMISSION IN STRAIGHT LINES AND REFLECTION

Sources of light.—The earth is at a distance of ninety-three million miles from the sun, yet it is upon the sun's heat and light that all forms of life depend for their existence. The earth's atmosphere deprives the sun's rays of much of their fierceness; nevertheless, the amount of heat actually received every year would melt a layer of ice surrounding the earth to a depth of about fifty yards. The stars are suns, each shining by its own light, and many of them much larger than the sun, but at vastly greater distances. On this account, the total amount of light received from all the stars is only about equal to that of a 16-candle power lamp placed at a distance of fifty yards. The moon and the planets reflect the light of the sun, and are not self-luminous; and the amount of light thus reflected by the moon is one hundred times that received from all the stars.

Certain insects, such as "fireflies", as well as a few other living things, can produce light by themselves; but practically the only source of natural light on the earth is that of the sun. All other forms of light, such as candles, lamps, fires, gas flames, and electric lights, are artificial sources produced by chemical or electrical action.

Radiation and light.—In a previous chapter it has been seen that the heat of the sun reaches the earth by radiation. These solar radiations comprise *sunlight*; they behave as if they are waves travelling through a medium pervading all space and substance, to which the name "the ether" has been given, and they may be referred to as ether-waves. These ether-waves are of various lengths, and can produce different effects. If they fall upon the

body, the longer waves may be absorbed, and the energy of the wave-motion becomes converted into **heat**; if they fall upon the retina of an eye, the shorter waves may produce a sensation of light and the waves are then spoken of as **light**; falling upon a photographic plate or upon a green leaf, the shortest ether-waves produce chemical effects, and are sometimes referred to as **actinic**. Things such as glass and water which allow light-waves to pass through them are said to be **transparent**, whereas things such as our bodies, the earth, wood and metals through which no light can pass are called **opaque**. The difference between the two classes of bodies is, however, not very clearly marked, since water in large masses is opaque, and ground glass, although some light passes through it, is not transparent. Gold, in very fine sheets, behaves in much the same way as ground glass, and bodies such as these are said to be **translucent**.

Light travels in straight lines.—Rays of light which have passed through a hole in the shutter of a darkened room can be seen to travel in straight lines. Though the light-waves are not themselves visible, yet the path of the light becomes apparent, because the particles of dust in the air are rendered luminous by the vibrations of the ether being reflected by them. If there were no dust particles in the room the beam of light would be invisible.

Another way of showing the path of light is to set up three vertical screens, each pierced with a small hole at the same height, and to set a candle or electric lamp behind one of them (Fig. 107). When

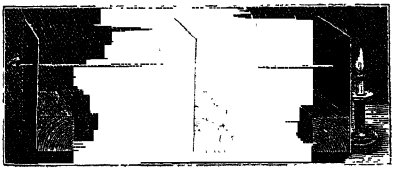


FIG. 107.—The light of the candle can only be seen when the three holes in the screen are in a straight line.

the screens are so arranged that the three holes are in a straight line, then the illuminated hole can be observed from the hole in the screen furthest from it. As soon as any one of the screens is moved,

the hole can no longer be seen. Thus light, and all other radiation, travels in straight lines.

Shadow of a rod.—When a ball is illuminated by a candle flame or a tiny electric lamp, the shadow of the ball thrown on a screen has sharp edges, and it is equally black throughout. This is another consequence of the fact that light travels in straight lines. The illumination may be regarded as coming from a single point S in Fig. 108. Rays proceed from S in all directions, and so illuminate

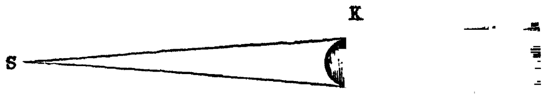


FIG. 108.—When the source of light is relatively small, the shadow of an object has no penumbra.

the whole of the screen with the exception of that part from which the rays are completely cut off by the opaque body (K).

Umbra and penumbra.—When the source of light is large, such as an electric light bulb of frosted glass or the opal glass globe of a lamp, the shadow formed is double, consisting of a dark, distinct shadow—the umbra—surrounded by a partially illuminated concentrically arranged shadow—the penumbra (Fig. 109). In Fig. 110,

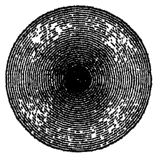


FIG. 109.—Umbra and penumbra.

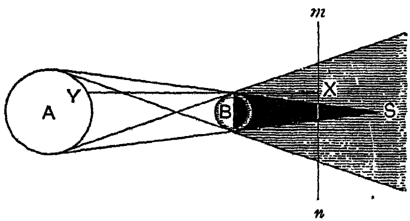


FIG. 110.—Formation of umbra and penumbra of a shadow.

A represents the illuminated globe, B the sphere, and mn the screen. Here the light is completely cut off from the small portion of the screen within the darkened cone. This is the umbra and corresponds with the whole shadow in Fig. 108.

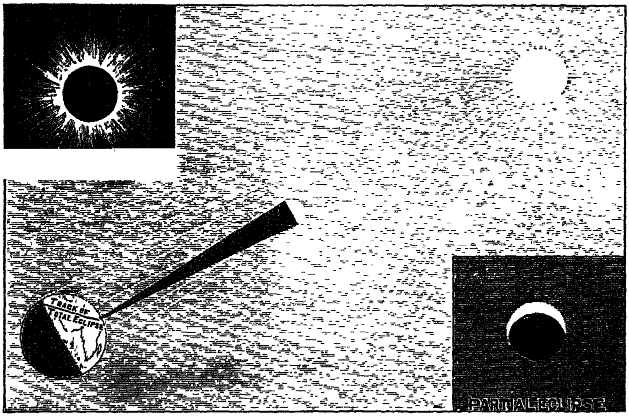


FIG. 111.—Partial and total eclipse of the sun.

Taking any point X in the penumbra, this receives no light from that part of A which is below XY, but it does receive light from that part which is above XY, so that it is only partially illuminated, whilst the rest of the screen outside the penumbra receives rays from the whole of the source of light.

Eclipses.—At certain times, the moon comes directly between the sun and the earth (Fig. 111); and, as it is an opaque solid, it blocks out the disc of the sun altogether along a narrow belt of the earth's

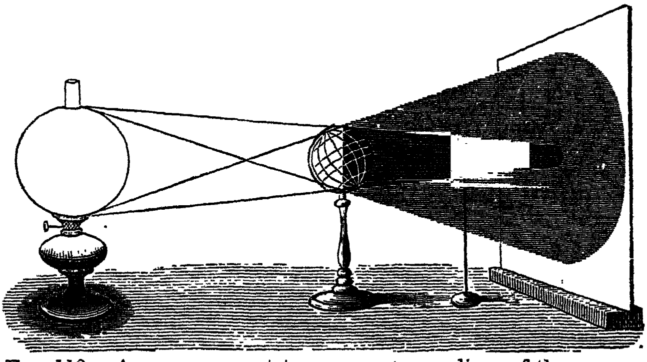


FIG. 112.—An arrangement to represent an eclipse of the moon.

surface. From any place within this belt a total eclipse of the sun is seen, but from points outside the belt the eclipse is only partial.

An eclipse of the moon occurs when the earth comes directly between the sun and the moon. Reference to Fig. 112 shows how this can be imitated experimentally. Here the lamp represents the sun, the central globe the earth, and the small black sphere the moon. If the moon passes into the umbra the eclipse is total, but if only a part of it is in the umbra a partial eclipse is seen.

Pin-hole camera.—When the path of a beam of light is made visible by dust, it is seen to be a straight line. That light travels in straight lines may also be inferred from everyday experiences. If light travelled through a constant medium such as air in lines that were sometimes bent, a beam of light from a motor-car headlamp, or from an electric torch, would illuminate objects hidden by, say, the corner of a house, and also it would be possible to see round a corner. Again, it is only necessary to put a small obstacle in the path of the light from a luminous body to shut out completely the view of it. The light from the setting sun, when the sky is cloudy, is often seen to travel in straight lines; the great beams of light which appear to spread out from the sun over a large part of the sky are made visible by the presence in the atmosphere of minute particles of dust and of water.

This property of light explains the little instrument known as a pin-hole camera. This consists of a box lined with black paper, one end of which is pierced with a pin-hole. The opposite end consists of ground glass or tissue paper. On pointing the pin-hole towards,

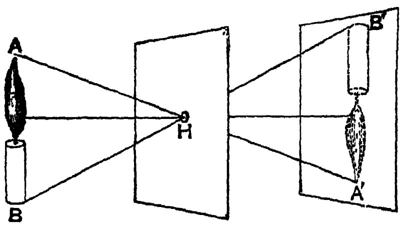


FIG. 113.—Explanation of the inversion of images seen through a pin-hole.

say, a lighted candle, an *inverted* image is seen on the tissue paper. By substituting a photographic plate for the tissue paper, it is possible to take photographs with such a camera, but long exposures are needed. The way in which the image is formed is indicated in Fig. 113. A ray from A can only reach the screen at A', while one from B can only reach it at B'. Similarly the paths of any rays starting between A and B can be traced, giving the resulting inverted image $A'B'$.

Candle power.—The term candle power has a definite meaning. It was fixed by the British Parliament in 1860 as **a candle of spermaceti wax, six of which weigh 1 lb., and burning 120 grains of wax per hour.** The intensity of the light given by an electric filament lamp is often stated in terms of candle power, although the candle is not now actually used for measurement. The modern standard in Great Britain is a lamp burning pentane under specified conditions, the illuminating power of which is equal to that of ten standard candles.

Reflection of light.—When any wave travels to the surface of a thing, and is thrown back from that surface and travels in a direction different from that in which it was originally moving, it is said to be **reflected.** This may happen in two ways, either **regularly** or **irregularly.** In the first case, it is turned back according to simple rules, while in the second there is no uniformity about the direction. The page on which this explanation is printed appears to be white, since—owing to the roughness of the paper—the light which falls upon it is reflected irregularly; a considerable amount of light is reflected regularly from a paper with a smooth "glazed" surface, and can produce an irritating glare which makes reading almost impossible.

Laws of reflection of light.—Light is reflected regularly from a plane mirror—that is, a flat reflecting surface. Such a mirror is generally made of bright metal or silvered glass. The angle between the direction in which the light-ray strikes the reflecting surface and the **normal** or perpendicular to the surface is called the **angle of incidence**, and the ray an **incident ray.** The angle between the direction in which the ray leaves this surface and the normal to the surface is known as the **angle of reflection**, and the ray, as it leaves, the **reflected ray.**

There is a definite connection between the angles of incidence and reflection, and it can be expressed as follows :

1. The line representing the reflected ray is in the same plane with the normal and the line representing the incident ray, and is on the opposite side of the normal to the incident ray.

2. The angle of incidence is equal to the angle of reflection.

Experiments have also shown that when a ray strikes a reflecting surface *normally*, it is reflected back upon the same line.

Formation of an image by a plane mirror.—These two rules enable the formation of an image by a plane mirror to be understood.

Let MM (Fig. 114) be the plane mirror, and A a bright point such as the head of a pin. The light ray which leaves A and strikes the mirror normally is reflected back along the same line, and the reflected ray appears to come from a point along AA'. A slanting ray, such as AB, is reflected in such a way that the angle of reflection CBD is equal to the angle of incidence ABC, and appears to an eye, placed as in Fig. 114, to come along BD from a point A', where BD produced meets AA'. If the same construction is made for any other ray AB', it will appear to be coming along $B'D'$, which produced backwards will pass through the same point A'. A' is therefore the image of A, and it can be proved that A' is as far behind the mirror as A is in front of it.

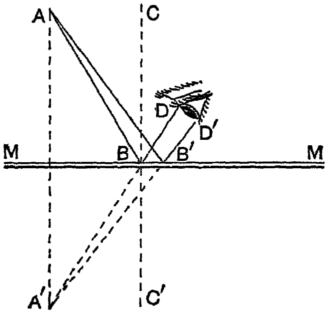


FIG. 114.—Representation of the course of rays producing an image in a plane mirror.

To find the image of an *object*, two or more points are chosen on the object, and the above construction applied to each point.

Reflection from spherical mirrors.—A spherical mirror is a part of a spherical surface which has the power of reflecting. It may be either *concave* or *convex*—the former if the reflection takes place from the hollow side, the latter if from the bulging side. The centre of the sphere of which it forms a part will still be the centre of the part of it constituting the mirror, and this point is called the **centre**

of curvature. The distance from this point to the mirror is called the radius of curvature. Thus in Fig. 115, C is the centre of curvature and CM, CD, CM' are all radii of curvature. MM' is called the diameter or aperture of the mirror and D is often called the pole of the mirror. A line going through the pole and the centre of curvature is the principal axis of the mirror. Every radius meets the mirror at right angles or is a *normal* to the mirror; it follows therefore that if a luminous object be placed at the centre of curvature, all the rays of light from it will be reflected back along the lines of incidence, or the image will be formed at the same place as the object.

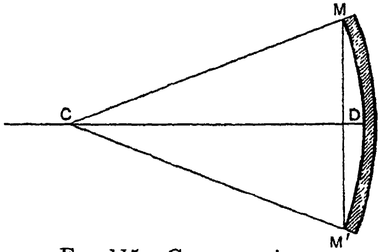


FIG. 115.—Concave mirror.

If *parallel* rays fall on a concave mirror—for example, rays from the sun—they will be reflected and brought to one point, called a focus. The point so obtained is called the principal focus of the mirror. In Fig. 116, F represents this point and C the centre of curvature.

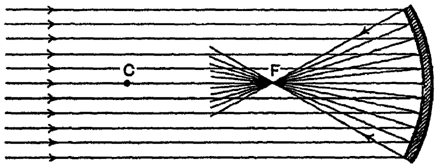


FIG. 116.—Principal focus of a concave mirror.

The parallel lines show the direction of the sun's rays. The point F is midway between the pole and C, or the focal length is half the radius of curvature. Conversely, a very bright source of light at the principal focus will give a parallel beam of rays. This principle is employed in motor-car headlights, which often consist of a small powerful electric lamp at the principal focus of a concave mirror fitted at the back of the lamp.

It is found experimentally that if a lighted candle or other small

illuminated object, such as a red-hot wire, is moved along the principal axis of a concave mirror, then an inverted image can be caught on a small paper screen so long as the illuminated object is farther away from the mirror than the principal focus. Such an image is said to be a **real image**. When the object is between the mirror and the principal focus, then an enlarged upright image is seen in the mirror, but it cannot be caught on a paper. Such an image is said to be a **virtual image**.

PRACTICAL WORK

1. **Rectilinear propagation of light.**—Take three cards and make a small hole in each with a fine needle. Fix the cards upon wooden blocks, or in clamps, so that all the holes are at the same height and in a straight line. Place a lighted candle or a lamp in front of the first card, and look through the third (Fig. 107). So long as the holes are in a straight line you can see the light from the candle shining through. Move one of the cards aside, and notice that you can no longer see the light.

2. **Shadows produced by small sources of light.**—Cast a shadow of a ball on to a screen, using a small source of light, such as a candle flame. Notice that the shadow cast on the screen is distinct, circular, and of equal darkness throughout.

3. **Shadows produced by large sources of light.**—(*a*) Use a "frosted" electric lamp and a ball smaller than the lamp bulb, and throw a shadow of the ball on a screen. Notice that the shadow on the screen is now made up of two parts—an inner dark circular patch called the umbra while concentrically arranged round it is a partially illuminated shadow, forming a ring, called the penumbra (Fig. 109).

(*b*) Using the same lamp, cast a shadow of a very small sphere. Move the screen slowly from the sphere, and notice that the shadow gradually becomes smaller and disappears. This is a *converging* shadow, while those of the two previous experiments are *diverging* shadows.

4. **Pin-hole camera.**—Construct a pin-hole camera as follows: Make two pasteboard tubes by rolling pasted paper on a wooden cylinder, so that one fits inside the other. Stick paper over one end of the wider tube and prick a hole in it. Line with black paper. Cover one end of the narrower tube with tissue paper, and thrust this end into the wider tube. Place the tube with the pin-hole facing a luminous object, such as a candle.

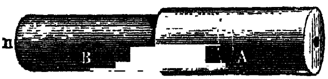


FIG. 117.—Pin-hole camera.

Notice that the image of the candle seen upon the tissue paper is upside down.

5. Pin method of proving the laws of reflection.—Fix two flat pieces of wood at right angles, as in Fig. 118, *AB*, *CD*. Against the upright slab put a strip of thin plane-glass mirror, *EF*. If possible the mirror should be silvered on the front surface. Upon the horizontal slab lay a sheet of white paper. Stick a pin *b* in the wood against the glass, and place another pin in the position *a*. Now procure a third pin and stick it into the wood at *c* in such a position that *c*, *b*, and the image of *a* are in a straight line. Draw with a finely pointed pencil a line along the edge of the glass *xy*; then take glass and pins away.

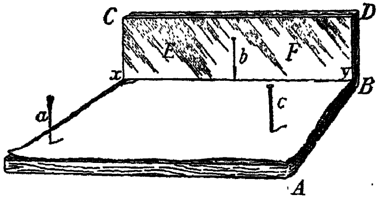


Fig. 118.—Arrangement of pins and mirror for proving the laws of reflection of light.

The paper will be marked by the pin-holes and the line *xy*. Draw lines through the pin-holes, and at *b* draw the normal *bd* to *xy*. Measure the angles *abd*, *cbd*, and compare them (Fig. 119). Repeat the experiment two or three times, with the pin *a* in different positions, and so determine the angle of incidence and the angle of reflection. Compare the two angles.

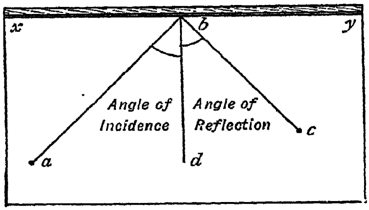


Fig. 119.—The angle of reflection *cbd* is equal to the angle of incidence *abd*.

Observe that since the holes made by the pins are all on the same piece of paper as the normal, *the incident ray, the normal, and the reflected ray are all in the same plane*. Moreover, the reflected ray is on the opposite side of the normal to the incident ray.

6. Images formed by plane mirrors.—Place a knitting needle in front of a narrow strip of plane glass mirror fixed vertically in front of a dark background. Arrange another such needle behind the mirror in such a position that wherever the eye be placed, the needle behind the mirror always appears in the position of the reflected image of the first needle.

Measure the distances of the two needles from the back of the mirror. Compare these two distances.

7. Principal focus of a concave mirror.—Cover a large concave mirror with black paper except for a small space at the centre, so that the

aperture of the mirror is small, or use a small mirror. Allow the parallel rays of sunlight to fall upon the mirror. Move a small paper screen to and fro in front of the reflecting surface so as not to cut off the incident rays. Notice that at a certain point—the principal focus—a clear image of the sun is formed, and probably the screen will be burnt.

8. Concave mirrors.—(*a*) Place a lighted candle in front of the concave mirror so that the flame is on the *principal axis* and beyond the principal focus. Move a small screen of white cardboard to and from the mirror so that it does not intercept all the light passing between the candle and the mirror. At a certain distance from the mirror a clear inverted image of the flame will be seen upon the screen.

(*b*) Now move the flame a short distance away from or towards the screen. The card must be moved towards or away from the mirror in order to obtain again a sharp image. This is a *real* image. On the other hand, if the flame is placed between the principal focus and the mirror, an enlarged upright image is seen in the mirror. This cannot be caught on a screen and is called a *virtual* image.

CHAPTER XIV

REFRACTION AT PLANE SURFACES

Refraction of light.—Up to the present, the light rays have been supposed to move through a uniform medium such as air. When this is so, light travels in straight lines, and, if it meets a reflecting surface, it is turned back, according to the laws already stated. If, however, the light passes from one medium into another of a different density, as, for example, when a beam of light from a motor-car headlamp is directed at an angle on to a pond of water, the path of the ray is no longer a straight line. The passage from one medium into the other is accompanied by a bending of its path. This bending is known as **refraction**, and the ray is said to be **refracted.**

Laws of refraction.—If a block of plate glass with parallel sides is laid on a sheet of paper and pins are arranged, two on each side of it (Fig. 120), so that, looking *through* the glass, they *appear* to be in a

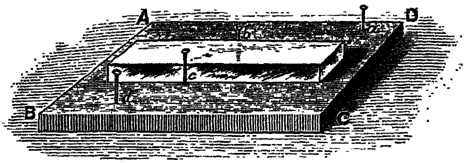


FIG. 120.—Pin method of illustrating refraction of light.

straight line, then on removing the glass and joining the pin-pricks by pencil lines, it will be seen that a ray of light is bent or refracted *towards* the normal on passing from one medium (air) to a denser medium (glass). Conversely, it is bent *away from* the normal on passing from a dense medium (glass) to a less dense medium (air).

Referring to Fig. 121, the angle of incidence *eba* is greater than the angle of refraction *cbf* on passing from the less dense to the denser medium; while on passing from the denser to the less dense medium, the angle of incidence *gcb* is less than the angle of refraction *dch*. The incident ray is parallel to the emergent ray when a parallel-sided glass block is used.

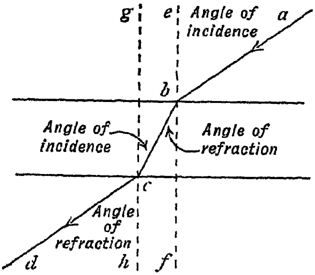


Fig. 121.—Diagram showing the course of a ray of light through a block of glass with parallel sides.

It may then be stated that

1. The incident ray, the normal and the refracted ray are all in the same plane.

2. The refracted ray is bent towards the normal on passing from the less dense to the denser medium, and vice versa.

Refraction through a plate with parallel sides.—In the case of a ray of light passing completely through a plate of glass having parallel sides, the ray is bent towards the normal when entering the glass, and away from the normal when emerging, so that its course is as shown in Fig. 122. The ray is thus displaced laterally or side-ways, but it emerges in a direction parallel to its original direction. The effect of refraction is in this case to cause an apparent change in the position of the object.

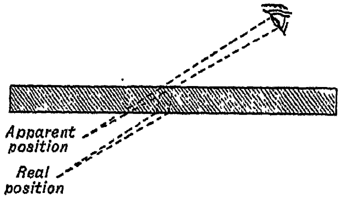


Fig. 122.—Refraction through a glass plate.

Various effects of refraction.—A coin at the bottom of a basin, hidden from view at first by the edge of the basin, becomes visible when water is poured into the basin. This can be explained by tracing out the path of the light.

In Fig. 123 let A be the position of the coin, in which it is just hidden by the edge of the empty basin, as shown by the broken line AE. After water has been poured into the basin, let a ray starting from A reach the surface at O. Such a ray passing from water into the air is bent away from the normal, ON, and can now reach

the eye, as shown in the diagram. To the observer, therefore, the coin now seems to be in the position *B*, due to refraction.

The refraction of light in its passage from one medium into another of different density explains several other familiar observations. It is well known that a stick or any other object held in a slanting position in water appears to be bent upwards. If a straight stick is fixed upright in water and looked at from a point a few feet above the end, it will appear shorter than it really is, in the proportion of

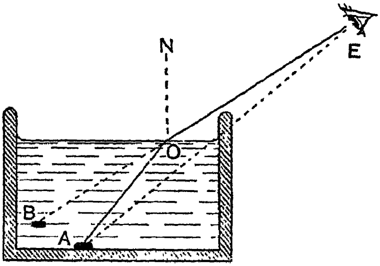


FIG. 123.—When the basin is empty the coin *A* is invisible to an eye at *E*, but when it is full of water the coin is seen at *B'*.

three to four, so that if a length of four feet is under water, it appears to be only three feet long. In the same way, ponds of water always appear shallower than they really are ; on account of refraction the bottom appears to be nearer the surface than it really is. A pool of clear water when viewed from a point vertically above the surface appears to be about three-quarters of its actual depth.

The light from the sun, moon, and other celestial bodies is bent, or refracted, when it passes through the earth's atmosphere and thus causes them to be seen in different directions from those which they really occupy. If, for example, *A* in Fig. 123 is imagined to be an observer on the earth's surface, and *E* the position of a body outside the atmosphere, represented by the water in the basin, then the object is not seen in its true direction *AE*, but in the direction *AO* produced. If the earth had no atmosphere, the sun would disappear from sight immediately it sank below the horizon, but, on account of atmospheric refraction, it is actually visible rather more

than two minutes after it is below the horizon, and it is seen about two minutes before it really rises.

If the earth had no atmosphere there would be complete darkness immediately the sun had set. The phenomena of twilight and dawn are due to the sun's rays falling upon particles in the high layers of the atmosphere and being reflected by them. Twilight ceases when the sun is 16 degrees below the horizon; and it is shorter near the equator than in higher latitudes because the sun's path cuts the horizon almost at right angles instead of obliquely.

The sun and moon appear flattened at rising and setting because of atmospheric refraction, the lower limb of either of these objects being raised more than the upper limb, and thus producing the appearance of a slightly oval instead of a circular disc.

Path of a ray of light through a prism.—The direction of a ray of light passing through a glass prism can be traced by using pins, as was done with a parallel-sided block of glass (Fig. 124).

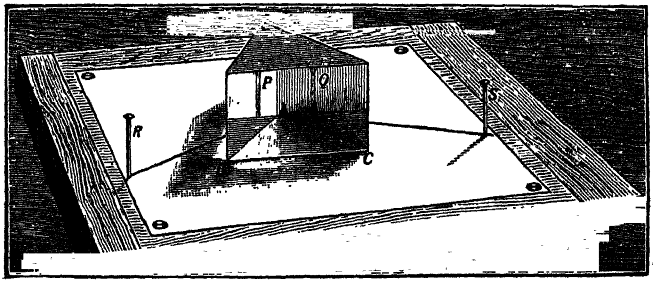


FIG. 124.—Pin method of tracing deviation of light by a prism.

In Fig. 125 let the triangle *abc* represent a section of the prism at right angles to its faces. Suppose DE is a ray of light striking the face *ab* of the prism. The light on entering the prism passes from the air into the glass, or from a rarer into a denser medium, and is bent *towards* the normal at the point of entry. It consequently travels along the line EE' until it reaches the face *ac* of the prism. Here it passes from the glass into the air—that is, from a denser into a rarer medium—and is, in such circumstances, bent *from*

the normal and travels along the line $E'D'$. In every such passage through a prism it is noticed that the light is always bent or refracted *towards the thick part of the prism.* An observer at D, looking through the prism, would see the point D', not at its real position at D', but at F, its apparent position.

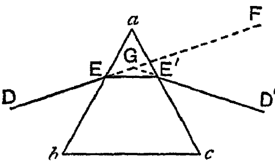


FIG. 125.—Construction to show the path of a ray of light through a prism.

Analysis of light by a prism.—When a beam of sunlight or other *white* light, as it is termed, from a slit is passed through a prism, it produces on a screen a band of coloured light, red at one end and passing gradually through orange, yellow, green, blue, indigo to violet (Fig. 126). The white light has been broken up and the components are defracted or bent by different amounts towards the base of the prism. The band of colour produced is known as a **spectrum**, and the light is said to be **dispersed.** An examination of the spectrum shows that one colour shades into the next. This is because the white light from the sun is composed of light of a very large number of colours, each of which is

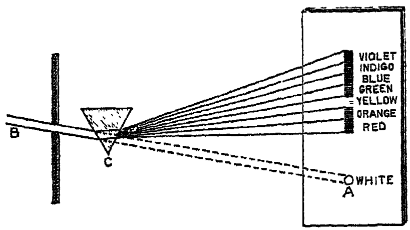


FIG. 126.—To illustrate the decomposition of white light by a prism.

bent by the prism to an extent depending on its colour, the red being least bent and the violet the most bent.

Refraction is accompanied by dispersion.—Cases of refraction of white light have been described as if all the components are bent equally, but the experiment with the prism shows that this is really not so. What is commonly called " red " light is not so much bent out of its path by a prism as " blue " light ; red light is said to be

less refrangible than blue light. A prism thus has the property of analysing or splitting up light into its component parts. White light is shown to consist of a complete range of colours shading from one to the next and going from red to violet; red light, produced by inserting a red glass screen in the path of the light before it reaches the prism, will give a spectrum showing a red patch in the same region as the red component of white light, with perhaps a few tiny patches further along the spectrum; and similarly other colours will give a prominent patch in the place appropriate to their colour.

PRACTICAL WORK

1. Pin method of finding laws of refraction.—Upon a piece of board *ABCD* (Fig. 120) place a sheet of paper, and upon the paper put a piece of fairly thick glass with parallel sides (a thick piece of glass from a box of weights, a paper-weight, or a number of microscope slides standing on their edges will do very well). Rule along the edges of the glass with a finely-pointed pencil. Place two pins *a*, *b*, one touching the side of the glass, as shown in the illustration, and then, *looking through the glass*, from the other side, stick in the pins *c*, *d*, so that all four appear in a straight line.

Now take away the glass and pins and join the pin-holes on the paper as shown in Fig. 121. Draw the normals *ebf* and *gch*. Measure the angles *eba*, *dch*, *cbf* and *gcb*. Repeat the experiment with *a* and *b* in different positions. Arrange *a* so that *ab* is at right angles to the edge of the glass and draw the direction of the ray.

2. Phenomena caused by refraction.—(*a*) Place a bright object, say a coin, on the bottom of an empty basin, and move the head until the object is *just* hidden by the edge of the basin (Fig. 123). Get somebody to pour water into the basin. It will now be possible to see the coin, due to refraction of the light rays.

(*b*) Fill a glass cylinder with water, and place a coin at the bottom. On looking straight down through the water the coin appears nearer the surface than it really is. Hold another coin near the outside of the cylinder, and place it at such a height that the two coins appear at the same level. The amount by which the coin in the water is apparently raised by refraction can thus be found.

3. Deviation by a prism.—Stand a prism upon one of its ends, upon a piece of white paper. Stick two pins into the paper in the positions *Q*, *S* (Fig. 124), place two more, *P*, *R*, on the opposite side of the prism, so that the four appear in a straight line *when looking through the prism.*

Draw the outline of the prism *ABC*, and then take away the prism and the pins and connect the pin-holes as shown in Fig. 125. It will be found that the ray is bent towards the base of the prism both when it enters and emerges.

4. Dispersion by a prism.—In a piece of card cut a slit about 2 cm. long and 1 mm. wide. Place the card, with the slit vertical, in front of a flat gas flame (Fig. 127). Arrange a prism on a stand, so that it is

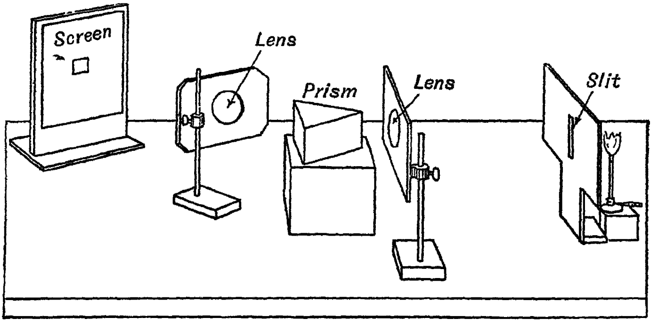


FIG. 127.—Experiment to show the dispersion of light by a prism.

at the same height as the slit and has its refracting edge vertical. Between the slit and the prism place a lens. Catch the light emerging from the prism by a second lens. Move the position of the screen until the coloured band of light is best seen. Observe that the light is refracted towards the base of the prism and that it is decomposed into constituent colours, which are differently bent by the prism. The violet light is refracted most and the red light least. Colours between these limits are bent by intermediate amounts. Name the colours you can see.

5. Dispersion a consequence of unequal refraction.—Place a red glass against the slit and notice that only a red image of the slit is visible. Still observing the screen, substitute a blue glass for the red one. A blue image is seen, but not in the same position as the red one ; the light producing it has been bent further away from the refracting edge of the prism.

CHAPTER XV

LENSES AND OPTICAL INSTRUMENTS

Refraction through a lens.—Most lenses are of glass with curved surfaces which are portions of spheres. In some lenses one surface is quite plane. All lenses can be divided into two classes—**convex lenses** and **concave lenses**. From the way in which they affect a beam of light, convex lenses are sometimes known as **converging lenses**, and concave lenses as **diverging lenses**. Convex lenses can be distinguished by their power of forming an image of a distant object like the sun, or by the fact that they can be made to magnify an object viewed through them. Concave lenses form no image in this way and have no power of magnifying; objects seen through them appear smaller.

Lenses may be regarded as being built up of parts of prisms in contact as shown in Fig. 128, where a convex lens is built up in this way. A ray of light falling upon any one of these prisms is refracted towards its thicker part, and consequently all the rays converge towards a point, which, if the incident rays are parallel, is known as the **principal focus** of the lens, as F in Figs. 128 and 129. Similarly,

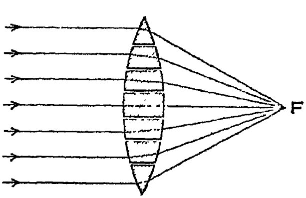


FIG. 128.—A lens built up of parts of prisms.

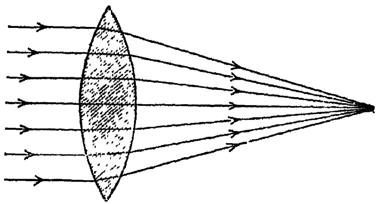


FIG. 129.—Principal focus of a convex lens.

if a source of light is placed at F, all rays from it which reach the lens are bent on passing through it and emerge parallel to one another. It will be noted that any ray passing through the centre of the lens is not bent from its straight line path. A straight line drawn through the centre of a lens and normal to its surface is termed the **axis**.

The magnifying glass.—These facts suggest a simple method of finding, by drawing, the position and size of an image formed by any lens. In Fig. 130, C is the centre of a convex lens, the principal

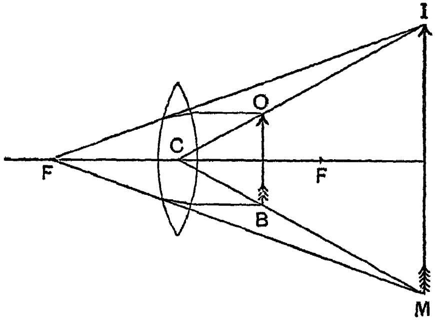


FIG. 130.—The magnifying glass.

focus of which is at F. An object represented by an arrow, OB, is between the lens and its principal focus. A ray of light from O parallel to the axis of the lens will be refracted by the lens and made to pass through the principal focus F (to the left). Similarly, a parallel ray from B will be refracted through F. Rays from O and B passing through the centre of the lens C are not deflected. Producing backward the four lines representing the rays, they are found to meet at I and M. Thus an eye placed to the left of the lens would see the magnified image IM. Since the rays do not actually go to I and M, the image is said to be virtual. Thus a convex lens produces an upright, magnified image of an object placed between it and its principal focus. Used in this way, the lens is often termed a **magnifying glass** or **reading glass**. It is sometimes referred to as a **simple microscope**.

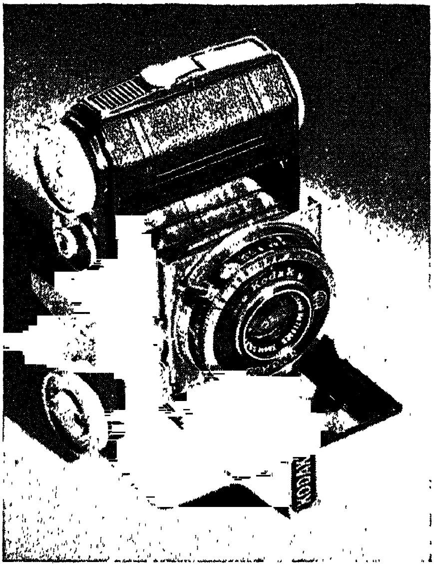


FIG. 131.—A modern folding camera partially opened.
(*By courtesy of Messrs. Kodak, Ltd.*)

The photographic camera.—In its simplest form this consists of a convex lens and ground-glass screen which can be moved towards or away from the lens until a sharp image of the object to be photographed is obtained (Fig. 132). The screen is then replaced by a prepared glass plate, coated with a substance, generally a compound of silver, which is highly sensitive to light. The plate is exposed to the light passing through the lens for a space of time varying from 1000th

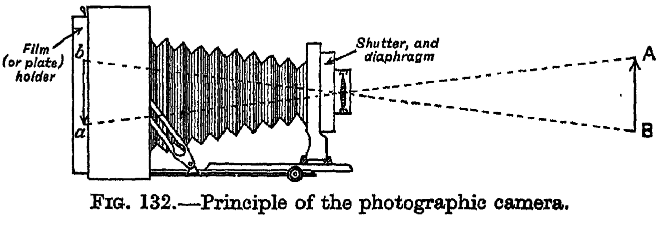


FIG. 132.—Principle of the photographic camera.

of a second to several minutes, according to the intensity of the light forming the image. The amount of light admitted to the camera is regulated by an adjustable aperture or diaphragm which is opened wide in a weak light and nearly closed in a strong light. The image is not visible until the plate has been "developed" and "fixed". In this way a **negative** is obtained in which light-coloured objects appear dark and *vice versa*. The **positive** or ordinary photograph is made by exposing sensitised paper to light through the negative; thus dark parts of the negative shield the sensitised paper, while light parts of it enable light to act on the paper, thus producing a positive effect.

The eye.—The eye may be regarded as a camera which takes temporary photographs or impressions, such impressions being then transmitted to the brain and giving the sensation of **sight**. The parts of the eye are seen in Fig. 133. The outer coating or **sclerotic**, *s*, consists of a tough skin which is kept firm by the presence of jelly-like substances, the **aqueous humour** and the **vitreous humour**. The sclerotic is transparent in front of the eye, where it is known as the **cornea**, *c*. By means of the **lens**, *o*, images are formed on the **retina**, *r*, which corresponds to the sensitive plate of the camera. The **iris**, *i*, serves the same purpose as the diaphragm of the camera; its opening becomes wider in a weak light and narrower in a strong light. The lens adjusts itself, altering its focal length according to the distance of the object seen. The cells of the retina are intimately connected with the ends of the **optic nerve**, *n*, by means of which the impression of sight is carried to the brain.

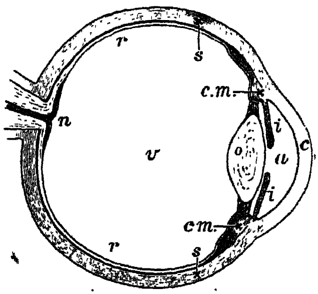


FIG. 133.—Section of the eye.

The microscope.—The simple microscope or magnifying glass consists of one lens only (see p. 143). The **compound microscope** consists of an **object glass** and an **eye-piece**, fitted in metal tubes which slide into a third tube so that the distance between them can be varied. Both object glass and eye-piece are composed of two or more lenses,

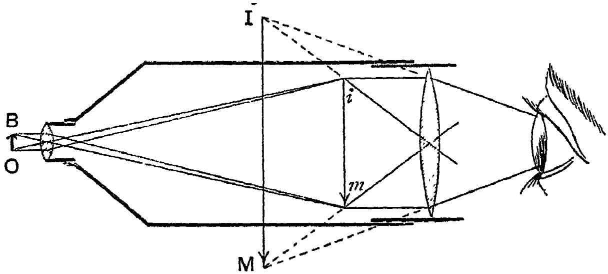


FIG. 134.—The compound microscope. The object glass (left) forms a magnified image *im* of the object *BO*; the eye-piece (right) forms a magnified image *IM* of *im*.

but the total effect is that of two convex lenses. The mode of formation of the image is illustrated in Fig. 134. The object glass forms an inverted image between the eye-piece and its principal focus; this image becomes the object for the eye-piece, which forms a magnified virtual image seen by the eye. By means of such an instrument, magnifications up to 250 times are readily given, and with more elaborate instruments much higher magnifications are obtained.

The optical lantern.—This is an apparatus for throwing an enlarged image of a transparent picture on a screen (Fig. 135). The diagram (Fig. 136) shows the arrangement of the necessary lenses. Here *L* is a source of light, an arc lamp or a powerful electric lamp. This light falls on a large lens *C* called a **condenser**; the light is made to converge on the transparent slide *AB*, which is thus strongly illuminated. Light from all parts of the slide passes through the lens *O* and a large inverted image of the slide is thrown on the

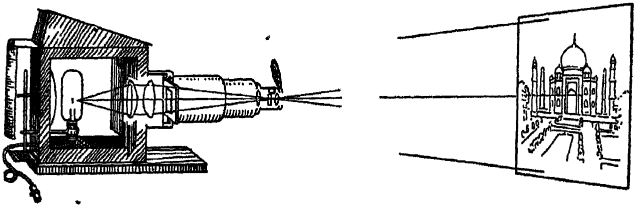


FIG. 135.—The optical lantern.

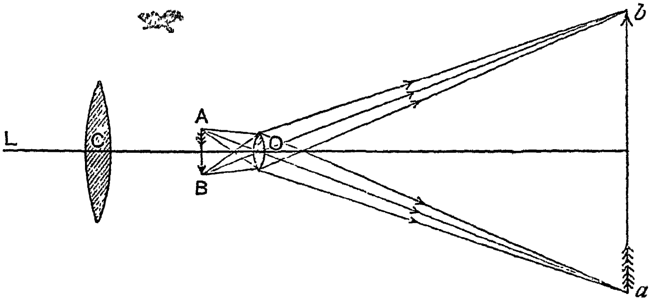


FIG. 136.—Principle of the optical lantern.

screen at *ba*. The slide must therefore be placed in the lantern upside down. A sharply defined image is obtained by moving the lens *O* ; this is known as **focusing**.

The epidiascope.—This instrument is used to produce on a screen a magnified image of a solid object or other opaque body, such as a picture. The object is illuminated by very powerful electric lamps, and the light reflected from it passed through a lens and focused on the screen as with a magic lantern. Special precautions have to be taken to get rid of the heat generated by the powerful lamps which are necessary.

The telescope.—The usual form of astronomical telescope, known as a **refractor**, consists, in its simplest form, of two convex lens, one a large **object glass**, and the other a smaller **eye-piece**. Each of these is made of two or more lenses, and the distance between object glass and eye-piece is adjustable for focusing. The principle of the instrument is illustrated in Fig. 137. The object glass *A* forms an image *im* of the object *BO*. This image becomes the object to the eye-piece, *E*. The position of the latter is adjusted so that the image formed by the big lens falls between the small lens and its principal focus. The second lens thus forms an enlarged image *IM* of the image *im*.

The largest astronomical telescopes consist of a big concave mirror, which reflects light accurately to a focus, where the image formed is examined by an eye-piece. Such a telescope is known as

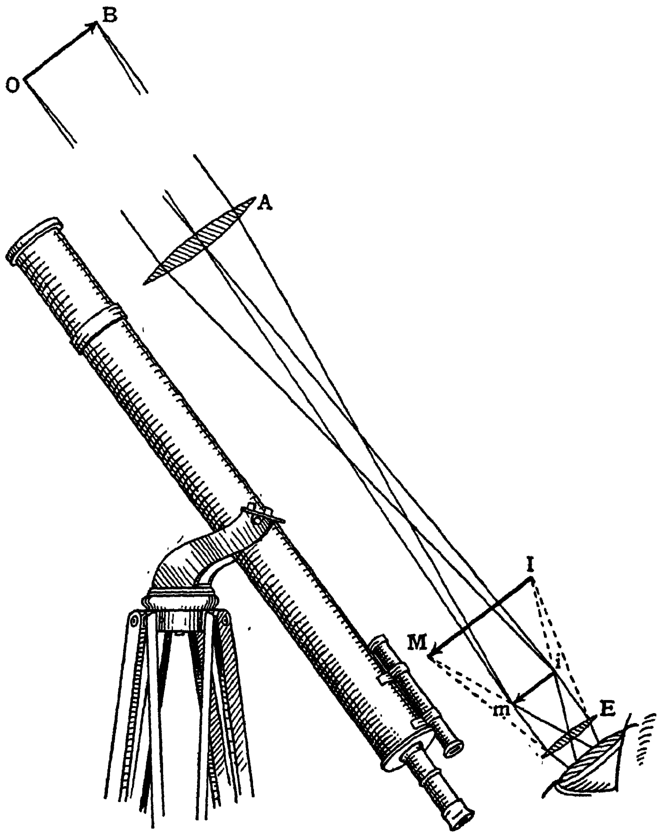


FIG. 137.—A small astronomical telescope, with a diagram illustrating the formation of the image. The small telescope near the eye-piece is used to find the object, before using the larger instrument.

a reflector. The biggest reflector in use is at Mount Wilson Observatory, in the United States, and it has a mirror 100 inches in diameter. A still larger one, with a 200-inch mirror, is being built.

The field or opera glass.—A simple form of field or opera glass is illustrated in Fig. 138. An object glass, *A*, a convex lens, form an

image *im* of the object *BO*. The rays forming this image are intercepted by a *concave* lens or eye-piece, *E*, the position of which is adjusted by focusing so that it forms a magnified image *IM* of *im*. It should be noted that the image produced by this form of field glass is erect, that is, is the same way up as the object, whereas the image produced by an astronomical telescope is inverted.

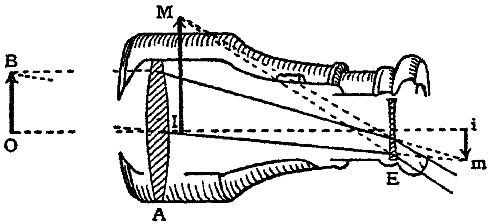


FIG. 138.—A simple field or opera glass, showing the formation of the erect image.

The cinema.—If a torch or a piece of glowing charcoal be rapidly rotated in the dark, the impression of a *circle* of fire is given ; during heavy rain the drops appear as continuous *threads* of water ; after looking at a strong light for a few moments and then closing the eyes, the image remains for a few seconds. The image persists on the retina for a minute fraction of time after the object is seen. This principle is made use of in the **cinematograph**, in which a series of photographs is taken of a moving object at the rate of about 16 to 50 pictures a second. When these pictures are projected in succession and at the same rate on a screen by a lantern similar in principle to the magic lantern, the impression of continuous motion is obtained, as the eye is incapable of distinguishing the separate pictures.

The photographs are taken on a long strip of photographic film by a special camera. The film passes behind the lens of the camera, stops for a fraction of a second, the lens is uncovered, a photograph taken, the lens covered again, and the film moves on in readiness for the next picture to be taken. In this way, as has been said, 16-50 pictures a second are taken. The film is developed in the usual way, producing a negative. From this a positive film is made.

The positive film, with its succession of pictures, is passed througl a projector, which is in principle a magic lantern, with mechanisn for carrying the film past the focusing lens. While the film is moving the lens is covered by a shutter, known as a "gate"; the filn is stationary for a fraction of a second, the gate is opened, an(the photograph is shown on the screen. Then the gate closes again the film moves on until the next photograph is in position behin(the lens, when the gate opens, allowing it to appear on the screen The speed of film and gate are adjusted so that they correspond t(that at which the photographs were taken. The result is a suc cession of pictures on the screen at intervals so short that th(eye cannot detect them, and the effect of motion is successfull; conveyed.

Sound films: the "Talkies".—At the present day it is usual fo sounds to accompany the pictures; and "silent films" are givin; place to "sound films". The sounds are allowed to act on a micro phone, an instrument which responds to sound waves by modifyin; minute electric currents passing through it. These changing electri(currents, in one system, control the intensity of a light, or, ir another, the movement of a spot of light. The changes in in tensity or the extent of movement are recorded on the edge of th(film on which the pictures are made.

The film is developed, and a positive obtained in the usual way When it is projected, the process of recording is reversed. A bean of light is made to pass through the edge or band of the film contain ing the sound record, and the variations in light intensity so pro duced, or the amount of light passing through, are directed on to a "photo-electric cell". This instrument responds to variations ir the light falling upon it by producing exactly corresponding minut(electric currents. These minute currents are magnified, or amplifie(as it is termed, in other apparatus, and the resulting electric current: are passed through a "loud-speaker", where they produce sounc vibrations corresponding with those which actuated the microphon(when the film was originally taken. In this way the sounds accom panying the incidents photographed for the cinema film are repro duced when the film is shown.

10. Poles of an induced magnet.—With the magnet and strip of iron in the same position, bring the far end of the strip near the poles of a compass needle and note the attraction for the south-seeking pole and repulsion of the north-seeking pole.

11. Induced polarity is temporary.—Remove the bar magnet and repeat the tests for magnetisation ; note that the strip now behaves as if unmagnetised.

CHAPTER XVII

STATIC ELECTRICITY

Electrification.—That some substances when rubbed acquire the power of attracting light bodies has been known from very early times. It was recorded by Thales (B.C. 600) that amber when rubbed became different from all other substances by possessing this power of attraction. The supposed cause of this property is called electricity, from the Greek word for amber (ἤλεκτρον). Until the end of the sixteenth century, amber was considered to be the only substance which could be made to attract light bodies after it had been rubbed. When, however, men began to observe and experiment, it was soon found that many substances behaved in a similar way. Substances which, like amber, became electrified by rubbing were called electrics.

It is now known that, under suitable conditions, most, if not all, substances can be electrified by rubbing with a suitable substance. A rod of sealing wax rubbed with flannel will cause quite a flutter among fragments of tissue paper; and a sheet of warm brown paper, after stroking with a brush, also will attract light bodies.

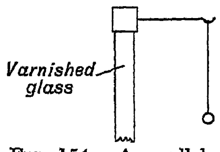


FIG. 154.—A small ball of pith suspended from a wire carried by a varnished glass stem detects electrification.

In order that these electrical effects may be well seen, it is essential that the materials used be quite dry.

Electrical attraction and repulsion.—Are all light bodies attracted, or only a selected few? Small balls of various substances are easily attached, by means of thread, to a support having a varnished glass leg (Fig. 154). Whatever the composition of the balls, all are attracted by an electrified rod.

If the electrified body itself is suspended (Fig. 155), any substance brought near it will attract it. Thus the attraction between a body

that is electrified and one that is not electrified is mutual; each attracts the other. When one of the suspended balls is allowed to touch the attracting rod, after a momentary hesitation it flies away and can not be made to approach the rod again.

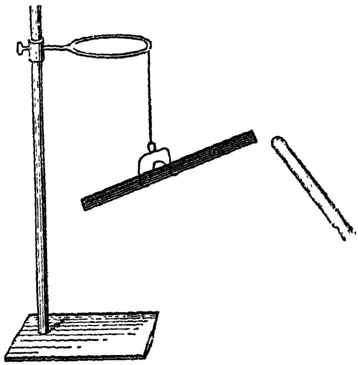


FIG. 155.—Experiment on electrical attraction and repulsion.

Two states of electrification.—If a suspended ball is *repelled* by a glass rod which has been rubbed with silk, a piece of sealing wax rubbed with flannel will *attract* it. Thus the sealing wax and glass, though both electrified, behave differently. It is found that all electrified bodies behave either like the rubbed glass or like the rubbed sealing wax. There are thus two states of electrification. It has been seen that when an electrified body shares its electrification with another body, the former immediately repels the latter; also it is found that a glass rod rubbed with silk will repel another similarly treated. Hence it may be concluded that **bodies similarly electrified repel one another.** Sealing wax rubbed with flannel will, however, attract a glass rod previously rubbed with silk. It may be stated, therefore, that **bodies oppositely electrified attract one another**; but, as in magnetism, attraction by a magnet is not proof that a body is magnetic, so attraction by an electrified body must not be considered as a proof of opposite electrification, for any electrified rod will attract an unelectrified body. Repulsion is the only sure test of electrification.

The names **vitreous** and **resinous** were given originally to the states of electrification of the glass and sealing wax respectively. When, however, it was found that glass rubbed with fur possessed the same kind of electrification as sealing wax rubbed with flannel, these names fell into disuse. Instead of vitreous and resinous, the words **positive** and **negative** are now used. Glass rubbed with silk becomes **positively electrified** (+ly), while sealing wax rubbed with flannel is

negatively electrified (– ly). When a body is electrified it is said to be **charged.**

Electroscopes.—An electroscope is an instrument for detecting the presence of small quantities of electricity. The instrument can also be used to determine the state of electrification. A suitably suspended ball of pith on a varnished glass leg, or on a stick of sealing wax, serves this purpose (see Fig. 154). Electrified bodies attract the ball. When, however, the ball is itself charged by touching an electrified body, it can be used to test the state of electrification. Bodies electrified in a similar way to the ball repel it; all other bodies attract it.

The **gold leaf electroscope** (Fig. 156) is much more convenient in use than the pith ball pattern. The metal wire, carrying the gold leaves at one end and a metal disc at the other, is supported inside a metal case with glass sides; the metal wire passes through a stopper of ebonite or sealing wax. The approach of an electrified body is indicated by the divergence of the leaves of the electroscope. Further, if the instrument is charged by contact with, say, a rubbed glass rod, its leaves diverge; the approach of any similarly electrified body causes more divergence, while the approach of an oppositely charged body causes them to close.

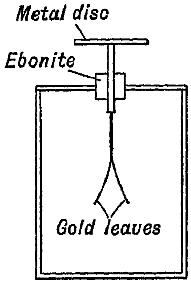


FIG. 156.—A gold leaf electroscope.

Equal and opposite charges are produced during electrification.—So far only the thing rubbed has been considered; the effect on glass has been observed, but not on the silk with which it was rubbed; the sealing wax has been shown to be electrified, but any effect on the flannel has been disregarded. Experiment with an electroscope shows, however, that not only is the rod electrified, but the rubber also, the electrification of one being of the opposite kind to that of the other. While the sealing wax becomes negatively electrified, the flannel is positively charged. If a body is rubbed and the rubber left in position, no trace of electrification can be observed. The charges are produced in quantities which balance one

another. When the bodies are separated, however, each shows its appropriate kind of electrification.

Conductors and insulators.—The reasons for many precautions, which it has been necessary to take, have not as yet been given. The varnished glass stand of the pith ball electroscope and the ebonite support of the metal carrying the gold leaves of the gold leaf electroscope are provided for a definite reason. When the cap of a charged electroscope is touched by the hand or a metal rod, its charge disappears. Recharged and touched by a rod of glass, ebonite or sealing wax, it is undisturbed ; its charge remains.

The metal rod and the hand **conduct** the electric charge away. Along the glass, ebonite, or sealing wax, the electric charge cannot escape. Substances which allow electricity to pass along them are called **conductors** ; ebonite and similar substances which prevent its flow are called **insulators**. Consequently, to preserve an electric charge, it must be separated from the earth by an insulator.

PRACTICAL WORK

1. **Electrification by friction.**—(*a*) Arrange some small light fragments of paper, rice husk or sawdust in a heap upon the table. Vigorously rub a dry rod of glass with a piece of dry silk and hold it over the light fragments. Observe how they are attracted by the rod.

(*b*) Repeat the last experiment using a stick of sealing wax and flannel, a rod of ebonite and a piece of fur, and a sheet of brown paper and a brush.

To obtain satisfactory results the rods and rubbers should be quite dry and warm.

2. **Electrical attraction and repulsion.**—(*a*) Make a stirrup of stout copper wire. Hang it from the ring of a retort stand by means of a thread of silk. Balance a strip of wood in the stirrup. Electrify a rod by rubbing and bring it near to the balanced strip. Notice attraction.

(*b*) Using light rods of other substances than wood, observe that all are attracted by the electrified body.

3. **Two kinds of electrification.**—(*a*) Rub a piece of glass tube with a piece of dry silk, and support it on the hanging stirrup. Then rub a piece of sealing wax with flannel and bring the rod of sealing wax near the glass tube. Notice *attraction*.

(*b*) Support one piece of glass tube which has been rubbed with tl silk rubber and bring up a second glass tube which has been similarl treated. Notice *repulsion*. Repeat the experiment using two sticks (sealing wax and a flannel rubber.

4. The electroscope.—Suspend a ball of pith by a thread of silk froı a wire stuck into a piece of sealing wax. Electrify a glass rod by rubbir with silk and bring it near the suspended ball. The ball is attracted t the glass, touches it, and then springs off ; it is then repelled whenev(the electrified glass rod is brought near it. By contact with the gla: rod, it has obtained a charge of the same kind (+) as the glass, an hence is repelled. Bring a piece of sealing wax electrified by rubbin with flannel near the charged suspended ball. The ball is attracte(and so long as it does not touch the sealing wax, it continues to t attracted. The charged ball therefore indicates the kind of electricit; positive or negative, on a body.

5. Equal and opposite charges.—Make a flannel cap just to fit tl end of a stout rod of sealing wax or other convenient substance. Attac a silk thread to the flannel cap. Rotate the flannel cap once or twic by pulling the piece of silk which has been previously wound round it.

(i) Holding the cap by the silk thread, bring it near a +ly charge ball. Notice repulsion. The cap is therefore +ly charged.

(ii) Touch the pith ball with a finger, and then charge it negativel by means of a piece of sealing wax rubbed with flannel. Bring near the end of the rod on which the flannel cap has been rubbed. Agai notice repulsion. The rod was therefore −ly charged by the flann cap.

(iii) Put on the cap again and repeat the rubbing. Do not take o the cap, but bring both up to an uncharged pith ball. There is neith(attraction nor repulsion, showing that equal but opposite charges aı produced.

6. Conductors and insulators.—(*a*) Rub with a piece of dry silk brass tube held in the hand. Bring the tube near the metal disc of charged gold leaf electroscope.

(*b*) Hold a piece of brass tube into which a varnished glass rod ha been pushed, and without touching the metal with the hand, flick tl brass with silk or with a piece of fur. Now quickly bring the brass i contact with the cap of the electroscope. Compare the result with tha obtained in (*a*).

(*c*) Cause the leaves of an electroscope to diverge widely by means (small positive charges. Touch the disc of the electroscope in successic with pieces of glass, sealing wax, solid paraffin, ebonite and a piece (metal.

Charge the electroscope again and touch the disc with the finge Record the results.

CHAPTER XVIII

CURRENT ELECTRICITY. MAGNETIC EFFECTS

The simple cell.—When a piece of commercial zinc is placed in dilute sulphuric acid, bubbles of gas escape from the liquid. This is an example of **chemical action.** Some of the zinc dissolves in the acid, while a new substance, the gas hydrogen, makes its appearance. A rod of copper or rods of pure or amalgamated zinc (that is, clean zinc upon which mercury has rubbed) are unaffected by dilute sulphuric acid; consequently, on placing copper and amalgamated zinc rods in the acid, without bringing them into contact, no effect is observed; when the metals are made to touch—either inside or outside the liquid—bubbles of hydrogen are rapidly given off from the copper plate. This connection of the metals, therefore, is an essential condition of activity in the cell. The metal plates need not actually touch. If they are connected by means of a wire outside the liquid the same effect takes place.

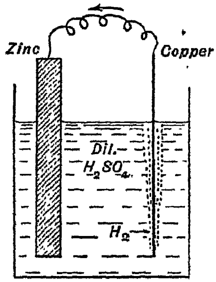


FIG. 157.—Simple voltaic cell.

If a small magnetic needle is brought near this wire, the wire is found to have acquired a new power. The needle is disturbed as though by another magnet. Similarly, if the wire is wound round a piece of soft iron and its ends kept in contact with the metals, the soft iron becomes a magnet under the influence of the wire connecting the metal plates.

The wire is said to have an **electric current** passing along it. The current is assumed to flow, outside the liquid, from the copper to the zinc (Fig. 157). The part of the copper plate outside the liquid is called the **positive pole**; and the part of the zinc plate outside the

liquid is termed the **negative pole**. This apparatus for producing an electric current is known as a **simple voltaic cell.**

Difference of electrical levels or potential.—When a vessel containing water is connected to another vessel which is empty, or which contains water at a *lower level*, water flows from the first vessel into the second until the levels are the same (p. 11). Similarly, if a body at a high temperature is placed in contact with a body at a lower temperature, a *flow of heat* takes place from the former to the latter until both are at the same temperature or *level of heat* (p. 63).

A simple cell connected to a circuit may be compared to a system consisting of two large cans, one standing on a table and the other below it on the floor, the two being connected by rubber tubing on which is a spring clip. Work is done in lifting water to the level of the upper can, thus giving the water potential energy, which when the clip is released is utilised in producing a stream of water into the lower can. Similarly, by the solution of the zinc in the sulphuric acid, chemical work is done by means of which the copper is raised to a higher potential than the zinc, and a flow of electricity occurs from the copper to the zinc through the connecting wire. This is what is known as a **current**, and, as will be seen, such a current can be made to do useful work, just as a stream of water can be used for driving machinery.

The electrical pressure or difference of **potential** between the plates of a cell is known as the **electro-motive force** or **E.M.F.**, and this is the driving force which sends the current through the cell and the circuit against any resistance which may be present.

Polarisation.—The electric current in the wire from a simple cell is neither permanent nor constant; it wanes and finally ceases. Simultaneously, the action in the liquid ceases, and the copper is found to be covered with bubbles of gas. On brushing these off, the chemical action in the cell recommences, and a current again flows through the wire, which regains its power of influencing a magnet. The gas on the copper plate appears to choke the cell. This effect is called **polarisation**. A cell so impeded is said to be polarised.

The simple voltaic cell, owing to polarisation, is not of practical importance. The cells in common use get rid of the obstructing gas

either by mechanical or chemical means. Cells depending on the first method have the negative plate roughened to help the escape of the gas. Those in which chemical means are used are of several types.

Daniell cell.—In most of the cells in which polarisation is prevented by chemical means, there are two vessels, one placed inside the other. The inner is made of porous earthenware which permits a slow passage through it of the liquids on either side of it. In a Daniell cell (Fig. 158) the outer vessel is of copper and serves as

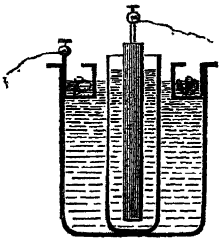


FIG. 158.—A Daniell cell.

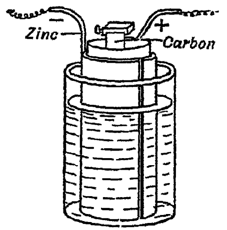


FIG. 159.—A Bunsen cell.

the copper plate. This outer vessel contains a solution of copper sulphate (blue vitriol), the strength of which is maintained by placing some crystals of the same substance on a tray, which extends round the top of the inside of the copper vessel. The inner porous pot contains dilute sulphuric acid into which dips a rod of amalgamated zinc. In this cell the hydrogen, which would otherwise be deposited on the copper vessel, acts on the copper sulphate and converts it into sulphuric acid, while the copper from the blue vitriol is harmlessly deposited on the copper vessel.

Bunsen cell.—In a Bunsen cell there are also two separate vessels; the inner smaller one alone is porous and is filled with concentrated nitric acid, into which a piece of hard carbon dips. The outer vessel contains dilute sulphuric acid, and in it is placed a zinc plate, which is usually made cylindrical in shape. The arrangement of the parts is shown in Fig. 159. The hydrogen-destroying agent in a Bunsen cell is the nitric acid. As soon as hydrogen is formed, instead of adhering to the carbon plate, it reacts with the

nitric acid, giving rise to poisonous red fumes which escape into the air.

The Leclanché and dry cell.—In the Leclanché cell a zinc rod stands in a saturated solution of ammonium chloride, and in a porous pot is a carbon rod closely packed round with manganese dioxide and powdered gas-carbon. When the poles of the cell are connected, the ammonium chloride acts on the zinc; hydrogen is formed at the carbon rod but oxygen from the manganese dioxide combines with it to form water and so removes polarisation. A Leclanché cell soon becomes temporarily polarised, but recovers, and so is used for telephones and electric bells where the current is only needed for short intervals. The **dry cell** differs from the Leclanché in having no liquid to be spilled. The outer part is packed with sawdust or plaster of Paris saturated with ammonium chloride solution. The zinc generally forms the outer casing of the cell (Fig. 160).

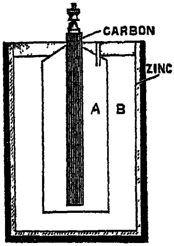


FIG. 160.—A dry cell. *A* contains manganese dioxide and powdered carbon; *B* contains plaster of Paris saturated with ammonium chloride.

The accumulator.—The accumulator, often known as a **secondary cell** or a **storage cell**, differs from the cells already described in the fact that, before a current can be obtained *from* it, a current must first be passed *through* it for a considerable time. In practice a

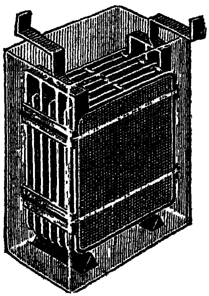


FIG. 161.—An accumulator.

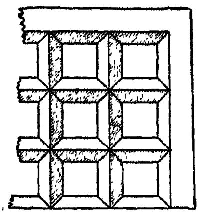


FIG. 162.—Grid of an accumulator.

current from a dynamo is passed through—in at the positive plates, which are marked with red, and out at the negative—for about thirty hours. The original type of accumulator, devised by M. Planté, consisted of two sheets of lead rolled up together and separated by felt or similar material, and immersed in dilute sulphuric acid (specific gravity 1·20). When a current is passed, electrolysis takes place, oxygen and hydrogen being formed. The oxygen formed at the positive pole attacks the leaden plate, forming a coating of lead peroxide. After some time, if the charging is discontinued and the two plates joined up externally, a current is found to flow from the highly oxidised plate to the other plate.

The plates in modern accumulators are made in "grid" form, with a paste of lead oxides and sulphuric acid pressed into the spaces; this facilitates the formation of lead peroxide. During the discharge the lead peroxide is attacked by hydrogen with the formation of lead monoxide and water. The strength of the sulphuric acid is reduced by the water thus produced, so the specific gravity of the weakened acid becomes less than 1·20. Hence, if on testing the specific gravity of the acid with a hydrometer (p. 5), it is found to be less than 1·20, the accumulator is run down and needs recharging.

The accumulator, when charged, has a high E.M.F. and a very low resistance, so that it is suitable for supplying large steady currents.

Arrangement of cells in batteries.—When a greater current is required than can be given by a single cell, several cells are joined together, and the resulting combination is known as a battery of cells.

If the current has to be driven through a long outside circuit, the cells are arranged in series as in Fig. 163 (*b*) and (*c*). Here the positive

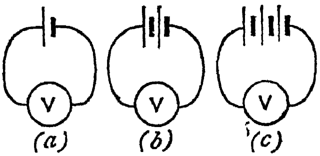


FIG. 163.—Cells in series.

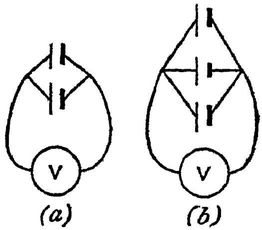


FIG. 164.—Cells in parallel.

pole of one cell is connected to the negative pole of the next, and so on.

When the outside resistance through which the current has to pass is very low, or when a very large current at low pressure is required, the best arrangement is in **parallel**, all the positive poles being joined together and all the negatives joined together as in Fig. 164. In the figure, *V* represents a **voltmeter**, which is a special kind of galvanometer (p. 177) for measuring the **electro-motive force** or driving power of the battery. The total E.M.F. of cells arranged in series is roughly equal to the sum of the E.M.F.'s of the separate cells; when they are in parallel, it is equal to the E.M.F. of one cell only.

Magnetic field due to a current.—Magnets placed in the neighbourhood of an electric current are influenced by it. Electric currents create magnetic fields around themselves. The strength of such a magnetic field is found to depend on the strength of the electric current, and the direction of the lines of force to depend on the direction of the electric current. If a small pivoted magnet is moved near a vertical wire along which an electric current is flowing, the needle tends to set itself at right angles to the line joining its centre to the nearest part of the wire.

In order to investigate the nature of this "field", the following experiment may be carried out. A small hole is bored in a piece of smooth white cardboard, and the cardboard fixed in a horizontal position by means of a clamp attached to a stand. A length of thick copper wire is passed through the hole, and is firmly clamped so that it is at right angles to the cardboard. Fine iron filings are sprinkled on the cardboard and a strong current is passed through the wire—a battery of large accumulators with a suitable resistance being used if available. On tapping the cardboard gently and then breaking the circuit, it will be found that the filings form circles around the wire (Fig. 165).

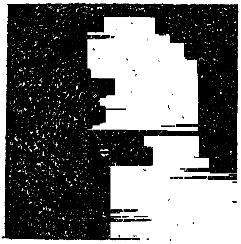


FIG. 165.—Map of the magnetic field perpendicular to a wire conveying a current.

If a spiral of wire is used, a magnetic field is obtained which very closely resembles that given by a bar magnet (compare p. 154). A spiral of cotton-covered wire is wound on a cardboard tube about 5 cm. diameter and 20 cm. long, and a piece of paraffined paper is cut so that the tube fits into it with its axis in the plane of the paper and a "tongue" of the paper passes through the tube. On passing a current through the spiral and sprinkling iron filings on the paper, a "map" is obtained as shown in Fig. 166, which should be carefully compared with that of a bar magnet. Thus a spiral of wire, which is called a **solenoid**, through which a current is passing gives rise to a magnetic field almost identical with that of a bar magnet.

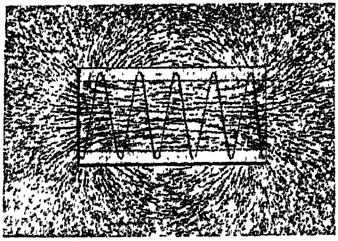


FIG. 166.—Magnetic field due to a spiral conveying a current.

The resemblance to a magnet can also be demonstrated by floating cells. A primary cell is made by passing zinc and copper strips through a large cork so that they can stand in a beaker of dilute sulphuric acid. A solenoid of light wire is joined to the zinc and copper strips, and the complete cell made to float in a bowl of water by means of cork (Fig. 167). If one pole of a magnet is placed near the solenoid, its ends are attracted or repelled just as if it were itself a magnet. Also two such coils react on one another in quite a similar way.

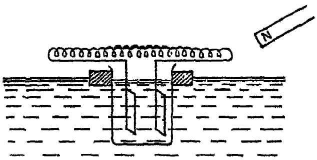


FIG. 167.—A floating solenoid.

Electro-magnets.—A coil of wire conveying a current can thus act like a magnet. On placing an iron core inside the coil its magnetic strength is greatly increased. For the time being, the iron becomes a magnet, and the magnetic power of the combination exceeds that of the current alone. Such a combination is called an *electro-magnet*

(Fig. 168). When the iron core is bent into the form of a horse shoe, the horse-shoe electro-magnet results (Fig. 169). In winding this form of magnet, care must be taken that the ends of the horse shoe are of opposite polarity. For lifting purposes the horse-shoe form of magnet is very effective.

By employing special iron alloys containing nickel and aluminium, many turns of wire and a strong current, an electro-magnet of enormous power can be made, such as is used with a crane for lifting iron parts, scrap, etc. (Fig. 170).

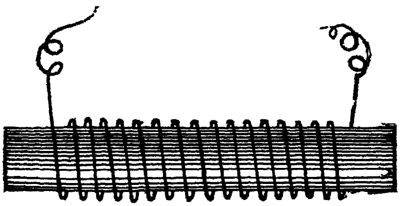


FIG. 168.—An electro-magnet.

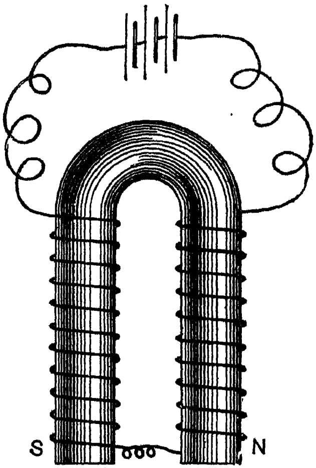
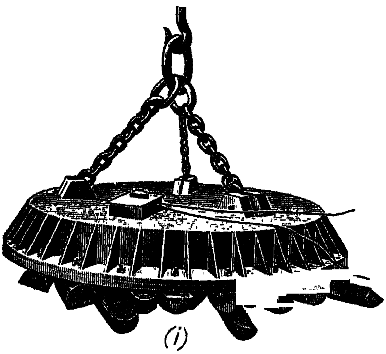


FIG. 169.—A horse-shoe electro-magnet.



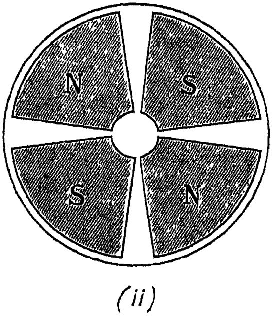


FIG. 170.—Electro-magnet for lifting iron scrap, etc. (i) The magnet is suspended from the hook of a crane and is "lifting" pig iron. (ii) Plan of the magnet with the pole-pieces marked.

Ampère's rule.—It is often desirable to know in what direction a ıagnet which is being influenced by an electric current will be eflected, or, from the magnet's ıovements, to determine the direcon of flow of the current. By lacing a wire carrying a current ı various positions near a compass eedle, a simple relation is disɔvered between the direction of ıovement of the marked pole and ıe direction of the current. The ;atement of it is known as **Ampère's** **ıle**, and may be expressed thus: *If a man were to swim along a wire ı the direction of the current and always facing the magnet, the marked r north pole tends to move towards his left hand* (Fig. 171). This ıle applies whether the circuit passes *above* or *below* the magnet pole.

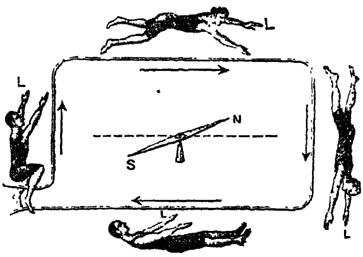


FIG. 171.—Ampère's rule.

Galvanometers.—An electric current is detected by the deflection f a magnetic needle in its immediate neighbourhood. An instruıent based on this principle is called a **galvanometer** (Fig. 172). The

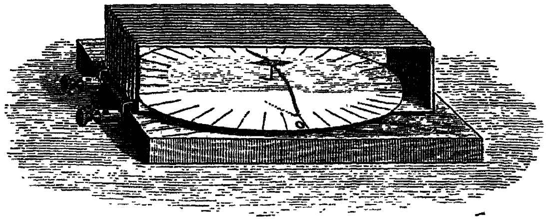


FIG. 172.—A simple galvanometer. The short compass needle has a light pointer fixed at right angles to it.

urrent passes both below and above the magnetic needle many imes, since the coil consists of many turns; hence from Ampère's ule applied to each part of each turn of the wire, the tendency is verywhere to move the magnet pole in the same direction. The ffects are thus added together in the instrument, so that even a ery weak current can be detected. With the same current, the eflection shown by the galvanometer is greater as the number of

turns of wire is increased. To use the instrument, it is so arranged that the electric current, the direction and strength of which it is desired to measure, passes through the coil of wire round the needle. The coil itself is kept in the magnetic meridian parallel to the direction of the undisturbed needle. On the passage of the current the needle is deflected. From the angle of deflection of the needle, often indicated by a long light pointer on the needle and at right angles to it, the strength of the current can be calculated, if certain facts about the instrument are known.

This apparatus demonstrates the principle upon which instruments for measuring electric currents, such as ammeters and voltmeters, depend.

PRACTICAL WORK

1. **Preliminary experiments.**—(*a*) Place a strip of commercial zinc into a beaker of cold dilute sulphuric acid. Notice the brisk evolution of gas which takes place.

(*b*) Place a rod of pure zinc and the strip of copper into the dilute acid, taking care that the two metals do not touch one another. No gas is given off from either metal. Now tilt the pieces of metal towards one another until they touch outside the liquid. Observe that bubbles of gas appear on the copper plate.

2. **Amalgamated zinc.**—Prepare a plate of amalgamated zinc by dipping a plate of ordinary zinc into dilute sulphuric acid, and, after it has been acted upon for a minute or two, rubbing some mercury completely over its surface with a piece of cloth. Observe that amalgamated zinc, like pure zinc, does not cause evolution of gas in cold dilute sulphuric acid.

3. **Magnetic action of electric current.**—(*a*) Into some dilute sulphuric acid in a beaker place a plate of amalgamated zinc and one of copper, to each of which a copper wire is attached by a binding screw. Get an ordinary compass needle, and arrange matters so that the wire is parallel to the needle and in the same vertical plane. Notice the deflection of the needle.

(*b*) Wind a cotton-covered wire, which is connected with the copper and zinc plates, round a piece of galvanised iron as in Fig. 173. Notice that the piece of iron will attract iron filings.

4. **Polarisation.**—Repeat Expt. 3 (*a*), and notice that after a time the deflection of the magnetic needle becomes less. Rub the copper plate with a piece of wood until all the bubbles of gas have disappeared, and notice that the magnetic needle is again deflected.

5. Daniell cell.—Examine the parts of a Daniell cell. Connect covered copper wires to the binding screws. To charge the cell, fill the inner vessel with dilute sulphuric acid, and then three parts fill the outer vessel with copper sulphate solution.

6. Bunsen cell.—Examine a Bunsen cell. Fill the inner porous pot with concentrated nitric acid and the outer vessel with dilute sulphuric acid. A plate of hard carbon dips into the nitric acid and a cylindrical sheet of zinc into the sulphuric acid. Notice that a small spark occurs when the ends of the two wires from the carbon and zinc poles are brought together and separated suddenly.

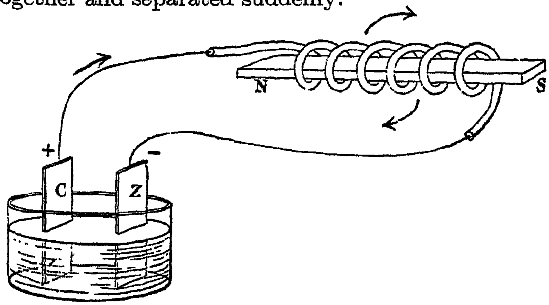


FIG. 173.—Magnetic action of electric current.

7. Direction in which a magnetic needle is deflected by the electric current.—(*a*) Using a cell, study the action of an electric current upon a compass needle placed in the magnetic meridian. Stretch a piece of covered copper wire, about a yard long, between two suitable supports, and arrange it in the magnetic meridian. Name one end *A*, the other *B*. Put a compass needle *under* the wire and let the needle come to rest; it will, of course, be parallel to the wire. Connect the wires from a single voltaic cell with the binding screws attached to the wire *AB*. Record the direction in which the marked end of the magnetic needle is deflected. Disconnect the wires from the battery, and reverse the connection with the wire *AB*. Observe that the marked end of the needle is now deflected in the opposite direction.

(*b*) Repeat the exercise, this time arranging the magnetic needle *above* the support.

Make a table of the results.

Direction in which current flows along wire *AB*	Position of needle	Direction of deflection of marked end of needle viewed from above
Example— *From A to B*	*below*	*to left*

8. Principle of the galvanometer.—Place the compass needle on a piece of cardboard, held horizontally in a clamp; now bend the wire *AB* so that the needle can be arranged in the loop of wire formed (Fig. 174). Arrange the loop of wire and the needle in the magnetic meridian, pass the electric current, and notice the amount of deflection of the needle.

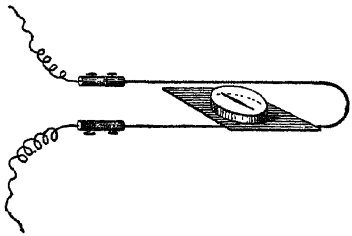


FIG. 174.—Principle of the galvanometer.

Now coil the wire so that there are two lengths above and below the needle, and repeat the previous experiment. The deflection of the needle is greater than before. This experiment illustrates the principle of construction of the *galvanometer*.

9. Magnetic field due to a current.—Arrange a wire, which connects the plates of a voltaic cell, in a vertical position. Hold a compass needle at the side of the wire and then move it slowly round the wire. Change the connections of the wire with the cell and try again. Record your observations. The needle always tends to set itself at right angles to the line joining its centre to the nearest part of the wire.

10. An electro-magnet.—Bind covered copper wire around a horse shoe, or a ∩-shaped piece of soft iron, so as to make an electro-magnet having opposite poles at the two ends (Fig. 169).

CHAPTER XIX

SOME APPLICATIONS OF THE ELECTRIC CURRENT

Resistance.—Metals in general are good conductors of the electric current, but they do nevertheless offer a small resistance to the flow of electricity. A water-pipe allows water to flow through it freely but at the same time it resists the flow to some extent, and it is common knowledge that by doubling or halving the area of cross-section of the pipe the rate of flow is doubled or halved respectively.

A similar result is found when a wire is carrying a current of electricity. The thinner the wire the smaller is the angle of deflection of the galvanometer needle—that is, the smaller is the current owing to the greater resistance. Again, increasing the length of the wire also increases the resistance. Whereas in the case of water flowing through a pipe, the material of the pipe makes little difference to the resistance it offers, it is found that, in the case of electricity flowing through a wire, the material of the wire makes a considerable difference. Iron wire offers a greater resistance than copper wire of the same diameter; no two metals have exactly the same resisting power.

It should be noted that in any circuit it is not only the wire connections which offer resistance to the current, but also the galvanometer, the cell, and any other unit, such as a lamp, which may be included. In the arrangement of cells in series and parallel, the internal resistance of a battery of cells when in series is much greater than when they are in parallel.

The electric lamp.—A fine wire offers greater resistance to the passage of an electric current than a thick wire. The resistance depends also on the metal of which the wire is made, copper conducting the current better than most other metals. When resistance is offered to a current, heat is produced. If the resistance is great and

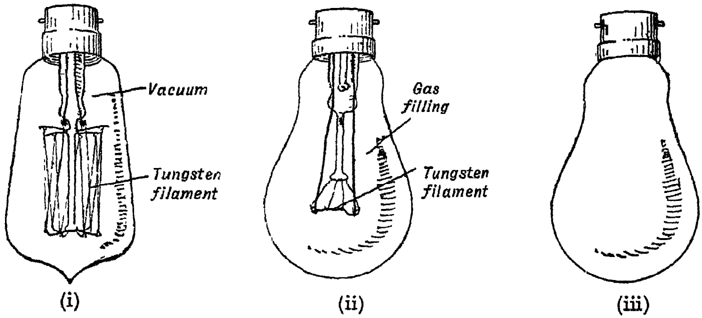
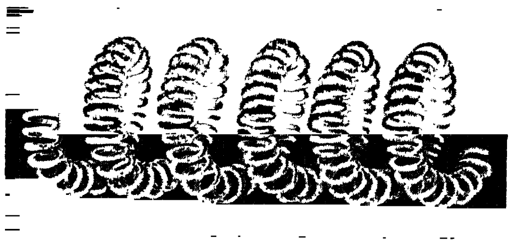


FIG. 175.—Filament electric lamps. (i) Lamp with long wire filament. (ii) Gas-filled lamp with the long wire coiled up making a short close spiral. (iii) Frosted lamp; the filament is not visible and there is much less glare when the lamp is alight.

the heat is generated rapidly, as in the case of a fine wire, this may become red hot or even white hot. A piece of thin platinum wire connected to a battery of two or three cells glows brightly almost immediately.

This effect is utilised in the ordinary electric lamp. The older lamps contain a filament of specially prepared carbon in a globe from which the air has been exhausted, since in the presence of air the carbon would burn away when it is heated to incandescence by the passage of the electric current. Filaments of the metals tanta-



Courtesy G.E.C. Ltd.

FIG. 176.—Magnified photograph of part of the "coiled-coil" filament of tungsten wire in a gas-filled lamp such as Fig. 175 (ii).

lum and tungsten are found to give a much stronger light, and to use less current, than carbon, and in modern lamps the latter metal has almost entirely replaced carbon. The so-called "gas-filled" lamps are exhausted, and then "washed out" with an "inert" gas such as argon or nitrogen. A little argon or nitrogen is allowed to remain in the bulb; it does not react with the filament and it makes the lamp last longer (Fig. 175).

In all such filament lamps the intense heat generated volatilises the filament slowly, and a dark deposit of carbon or metal appears on the glass with use. The glass of filament lamps is often "frosted" on the inner or outer side, in order to reduce the intense glare of the brilliant filament.

Vapour lamp.—Streets and large workshops are often illuminated with lamps giving a brilliant greenish or amber-coloured light. The light of these lamps is given out by a tube containing a little mercury or metallic sodium, which is heated by an electrical device until the metal is vaporised. The vapour carries the electric current or "discharge", and becomes brilliantly luminous, mercury giving a characteristic green light and sodium an amber light. Apart from giving a very powerful light, such lamps require less current than filament lamps producing the same intensity of light.

Mercury vapour lamps are also used in medical treatment. The light from them is very rich in ultra-violet radiation, which is found to have beneficial effects in certain cases on the human being.

Tubes containing a little of the rare gas, neon, give a brilliant red light when an electric current is passed through them. Such tubes are widely used in making illuminated signs for advertising and similar purposes (Fig. 177). The colour of the light can be changed by the addition of small quantities of other gases to the tubes.

The electric arc.—A powerful electric light is furnished by means of the electric arc. Two rods of compressed carbon are connected to the terminals of the electric main. They are allowed to touch and then drawn apart. A flash of light is seen, and this continues between the ends of the rods, which themselves become highly incandescent (Fig. 178). The end of the positive carbon, which burns away much more quickly than the negative, soon becomes

By courtesy of Messrs. Claude-General Neon Lights Ltd.

FIG. 177.—An illuminated sign, on the front of a house, and consisting of glass tubes containing neon through which an electric current is passing. Total height about 30 feet. Photographed at night.

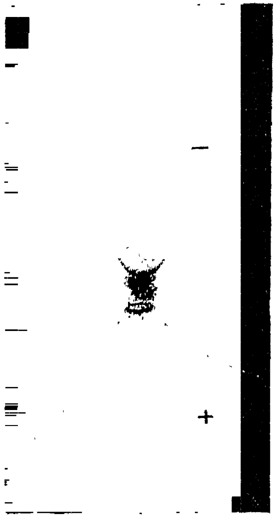


FIG. 178.—Electric arc. This form of electric light requires a big current, but gives a brilliant white light.

crater-shaped, whereas the end of the negative carbon becomes pointed.

Electric heating.—Where electrical power is available it is being increasingly used for domestic lighting and heating purposes. Electric cookers, radiators and fires are manufactured in great variety. They contain in all cases coiled wires of high resistance mounted on porcelain or some similar material, which is unaffected by red heat (Fig. 179). These wires are made of certain alloys such as nicrome (nickel 60, iron 25, chromium 15 parts) and manganin (copper 83, manganese 13, nickel 4 parts).

Courtesy G.E.C. Ltd.

FIG. 179.—Heating unit of an electric heater. The coil of wire wound on a porcelain rod becomes red-hot when a suitable electric current passes through it.

For industrial purposes electrical heating is used in the steel industry for welding and riveting ; two pieces of steel may be joined together by striking an arc between them.

The **electric furnace** is used very largely in the chemical industries. In one form of electric furnace, an electric arc burns inside an infusible covering of lime or magnesia, temperatures as high as 5000° C. being obtained. Amongst other purposes the furnace is used for making calcium carbide for the production of acetylene, and for the preparation of carborundum—the next hardest substance to the diamond.

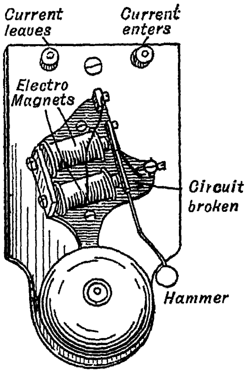


FIG. 180.—An electric bell. The electro-magnets are usually covered by a wooden case.

The electric bell.—The principle of the electro-magnet is utilised in the electric bell (Fig. 180), which consists of one or more electro-magnets and a hammer, which is made to vibrate against a metal gong. The binding screws are connected to a battery through a push-button. The hammer is attached to the frame of the bell by a flat spring, the free end of which presses against a pointed screw. When the circuit is completed by pressing the push-button, the current passes through this screw and spring and round the coils of the magnets. This magnetises the electro-magnets, which

consequently attract the hammer. When this happens the spring is drawn away from the pointed screw, and the circuit is broken at this point. In consequence, the electro-magnets lose their power, and the hammer being attached by the spring, flies back ; this causes the spring to make contact again with the pointed screw, thus completing the circuit again. The hammer is attracted again by the electro-magnets, and the process is repeated again and again, causing the hammer to vibrate rapidly against the bell or gong.

Induced currents.—A current passing along a wire causes a compass needle to be deflected. This is due to the magnetic field which the current produces. Conversely, when a magnetic field is produced near a wire, a momentary current is caused in the wire. A magnet brought up quickly to a coil of insulated wire connected with a galvanometer produces a momentary current in the coil, as is shown by the movement of the galvanometer needle (Fig. 181). With the magnet at rest, even with one pole within the coil, no current flows ; but as the magnet is withdrawn from the coil, a momentary current is again produced. It is important to notice that a current is *only* caused when the magnet is in motion—that is, when the number of lines of force in the neighbourhood of the coil is changing. Such currents are known as **induced currents.**

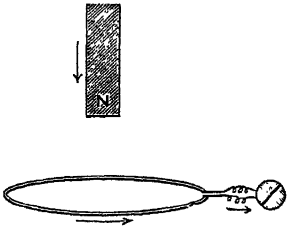


FIG. 181.—Production of induced currents by a moving magnet.

A rapid movement of a magnet near the coil of wire causes a greater deflection of the galvanometer than a slow movement—that is to say, the strength of the induced current depends upon the rate at which the number of lines of force passing through the coil changes.

The dynamo.—If a coil is arranged between the opposite poles of two large bar magnets, as in Fig. 182, then by turning the coil slightly on its axis, fewer lines of force will be able to pass through it ; that is, rotation of the coil changes the number of lines of force able to pass through the coil. Hence induced currents may be generated by its

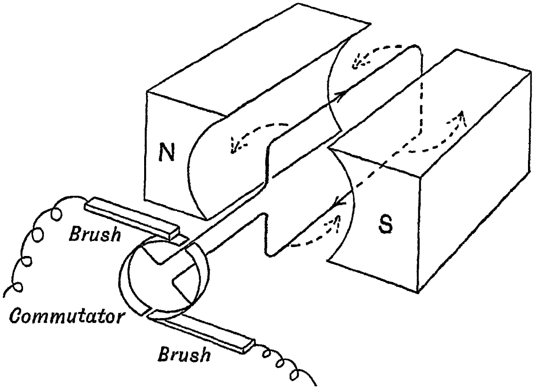


FIG. 182.—Production of induced currents in a coil moving between magnets. *N* and *S* are pole pieces of two large magnets which are omitted from the diagram.

rotation. By mounting such a coil on a spindle, it can be revolved continuously and the currents induced collected by connecting the ends of the coil to rings on the spindle (Fig. 183), so that sliding contact may be maintained during rotation. The current induced during the first half of a complete rotation (0°-180°) is in the opposite direction to that produced during the second half (180°-360° or 0°). Currents formed in this way, first in one direction and then in the other, are called **alternating currents**, and the machine producing them is known as an **alternator**.

If, however, a single ring or collar divided into two halves by two cuts along its length, known as a **commutator** (Fig. 184), is used for

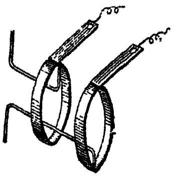


FIG. 183.—Collecting brushes of an alternator.

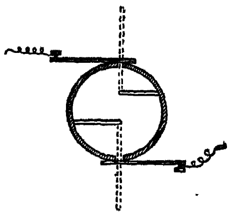


FIG. 184.—Commutator of a continuous current dynamo.

sliding contact, the current is picked up by each half of the ring alternately from the same end of the coil, so that the current delivered to the *outside* circuit is always in the same direction. A machine with this arrangement is called a **direct current dynamo.** In small models the coil or **armature** is sometimes made to rotate between the poles of a permanent horse-shoe magnet, called the **field magnet**, but in all practical machines the field magnet is an electromagnet (Fig. 185).

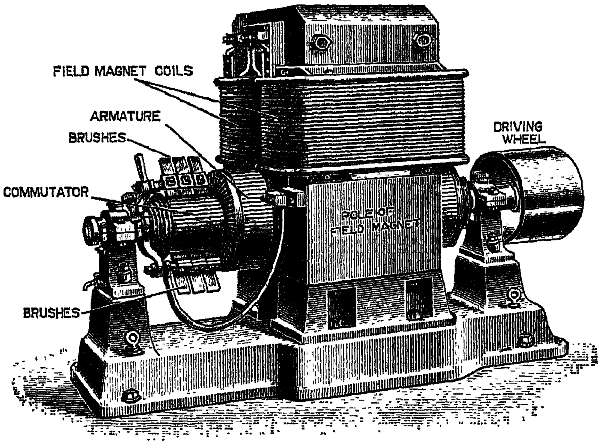


FIG. 185.—Direct current dynamo.

For producing powerful electric currents, huge spindles constituting the armature and consisting of many coils of wire are rotated by steam or gas engines, or by water-power, between the poles of powerful electro-magnets.

The electric motor.—When a coil is rotated by mechanical means between the poles of bar magnets, a current is induced in the coil. This is the principle of the simple dynamo. The process can be inverted. Let a current from an accumulator be passed into a coil free to rotate between magnetic poles ; then the coil itself will tend to rotate. This is the principle of the electric motor.

The current from a battery of accumulators or from a dynamo is

passed, by means of carbon "brushes", to a commutator which delivers current in the appropriate direction to a series of coils wound upon the **armature**. The armature is mounted so that it can revolve in the field of powerful electro-magnets, and as soon as a current passes through its coils, the forces acting on it make it revolve rapidly. By this means useful work can be performed.

From this it would appear that a dynamo and an electric motor are the same machine, converting mechanical work into electrical energy in one case and converting electrical energy into mechanical work in the other. In principle, this is true, but for practical reasons it is found to be desirable to design and build both dynamos and motors, according to the purpose for which they are required.

Electrolysis.—Water has a very high resistance and is therefore a bad conductor. When wires from a battery are dipped into a vessel containing pure water and a galvanometer is included in the circuit, then the galvanometer is almost unaffected, showing that practically no current passes. If, however, a few drops of sulphuric or hydrochloric acid, or of a solution of any metallic salt, are added, the current at once flows. Such substances are good conductors when in solution, and are known as **electrolytes**.

When a current passes through an electrolyte, the latter is decomposed and **electrolysis** is said to occur. Metallic compounds, when in solution or in a fused state, generally yield the metal and another product. Applications of this are found in the refinement of crude copper, the electro-deposition of silver and other metals, and in the commercial preparation of aluminium and sodium from fused bauxite and caustic soda respectively. The wires carrying the electric current to and from the solution or melt are known as **electrodes**.

Electrolysis of water.—When a current is passed through water made slightly acid, hydrogen is set free at the electrode which is connected with the negative pole of the battery, and this is called the **negative electrode** or **cathode**. Oxygen is formed at the same time at the **positive electrode** or **anode**. The vessel in which electrolysis takes place is known as a **voltameter**.

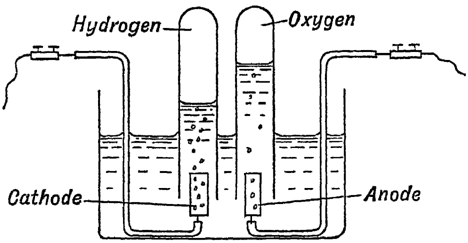


FIG. 186.—A simple voltameter.

A simple voltameter for the electrolysis of water is shown in Fig. 186. Two small plates of platinum to serve as electrodes are attached to two pieces of stiff, rubber-covered copper wire. The wires are bent as shown and stand in a dish of water containing a few drops of sulphuric acid ; two similar test tubes full of water are inverted over the electrodes. On passing a current, the water is decomposed, twice as much hydrogen being produced at the cathode as oxygen at the anode.

The electrolysis of water is used on a commercial scale for the production of these gases.

Electric fuses.—There is always a chance, when an electric current is used for lighting or for power, that for some reason the current may become too great and, by heating the conducting wires, may cause a fire. For this reason a safety-fuse is placed in the circuit. This consists of tin wire or tin-coated copper wire of such a thickness that if the current becomes greater than the conducting wires can safely carry, the wire melts or fuses and the current is automatically broken. The fuse wires are fixed in insulating boxes.

The fusing of a wire is often due to a **short circuit**. This is sometimes caused by faulty insulation, so that the bare wires come into contact before the current reaches the point where it is to be used. The resistance being thus lowered, a heavier current passes, the fuse wire is destroyed, and the current is automatically cut off.

The greatest care should be taken not to touch the wires or the terminals of an electrical circuit when a heavy current is passing, otherwise the person doing so may receive an **electric shock** which may

prove fatal. In addition to burns, a severe shock often causes asphyxia or suffocation, and in that case artificial respiration should be applied at once.

PRACTICAL WORK

1. **Resistance of wires.**—Set up a circuit containing a single dry cell and a galvanometer, using for one of the connections a long piece of thick copper wire (about 3 ft.); note the angle of deflection of the galvanometer needle. Replace the thick copper wire by thin copper wire of the same length, then by pieces of two, three and four times the length of the first piece; in each case note the reading of the galvanometer. Now, instead of the thin copper wire, use iron wire of the same thickness and length as the copper. Also, if available, try the effect of wires of other metals such as German silver.

Tabulate the results thus:

Kind of wire	Length of wire	Reading of galvanometer

2. **Heating effect.**—Using an accumulator, set up a circuit containing a long coil of thin iron wire immersed in water in a beaker. Take the temperature of the water before starting the experiment, and again after the current has been passing for some time. There should be a considerable heating effect.

3. **Induced currents.**—(*a*) Make a coil by winding cotton-covered copper wire round a 10 cm. cylinder about fifty times. Remove the cylinder and connect the ends of the coil to a sensitive galvanometer. Bring the north-seeking end of a bar magnet quickly to one side of the coil. Note the momentary deflection of the galvanometer needle. Now quickly withdraw the magnet; again note the momentary deflection, but in the opposite direction.

(*b*) Using the coil made in the last experiment, arrange it so that it stands on edge between the opposite poles of two bar magnets supported on blocks of wood. Connect the coil to a sensitive galvanometer (p. 177). Turn the coil quickly through 180° so that it again stands on edge. Observe the deflection of the galvanometer. Again turn the coil further through another 180°, so that it is once more in its first position, and note that the deflection is in the opposite direction.

4. **Passage of an electric current through acidulated water and through copper sulphate solution.**—Pour some water containing a little sulphuric

acid into one beaker, and a solution of blue vitriol (copper sulphate) into another. Connect them in series as in Fig. 187, *A*, *B*, *C* and *D* being carbon rods. *D* is joined to the negative and *A* to the positive pole of an electric battery. Pass a current through the solutions by means of four dry cells arranged in series.

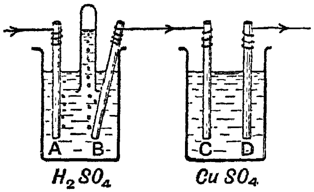


FIG. 187.—Electrolysis.

Bubbles are seen to form on *A* and *B*. Those on *A* are less plentiful than those on *B*. If the gases are collected by means of a test tube filled with water, the gas from *A* is found to be oxygen, and that from *B* hydrogen.

In the beaker containing the copper sulphate solution the rod *D* will now be found to be covered with a deposit of copper, whilst at *C* apparently nothing has happened.

5. The use of a fuse.—Using an accumulator or a battery, arrange a circuit containing a make-and-break key and copper wire connections. In a break in the copper wire fix a piece of magnesium wire or a piece of very thin iron wire, not allowing the current to pass until the arrangement is complete. Switch on the current. The magnesium or iron wire should be at once destroyed. It thus behaves as a fuse, automatically cutting off the current.

CHAPTER XX

ELECTRIC COMMUNICATION

The electric telegraph.—The principle of the galvanometer is made use of in telegraphy. The essential part of the receiving apparatus is in fact a galvanometer fixed vertically instead of horizontally (Fig. 188). The coil and magnetised needle are placed inside the instrument; the pointer, which is seen, is fastened to the axle of the needle. The needle, and of course the pointer also, is deflected when a current passes through the coil.

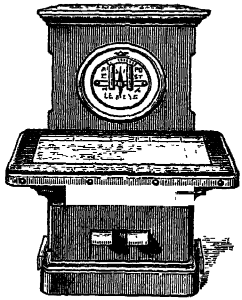


FIG. 188.—A single-needle telegraph instrument.

At the transmitting station is a battery and a commutator, as seen in Fig. 189. The commutator is connected with the receiving station by a long insulated wire supported on telegraph poles. The ends of the circuit are connected to metal plates, which are buried in the earth. By means of the commutator, a current may be transmitted to the receiving station

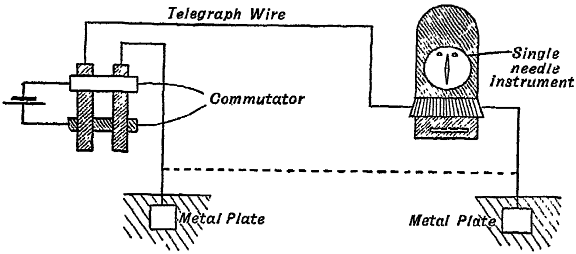


FIG. 189.—Diagram of a simple telegraphic system.

MORSE CODE

E	•	T	—		
I	• •	M	— —		Numerals.
S	• • •	O	— — —		
H	• • • •	CH	— — — —	1	• — — — —
				2	• • — — —
				3	• • • — —
A	• —	N	— •	4	• • • • —
U	• • —	G	— — •	5	• • • • •
V	• • • —			6	— • • • •
W	• — —	D	— • •	7	— — • • •
J	• — — —	B	— • • •	8	— — — • •
Y	— • — —	L	• — • •	9	— — — — •
F	• • — •	Q	— — • —	0	— — — — —
P	• — — •	X	— • • —		
R	• — •	K	— • —		
C	— • — •				
Z	— — • •				

either through the overhead wires and back through the earth or *vice versa*. Thus the needle is deflected either to the right or left. Hence two types of signal can be sent or received; and to be able to send an intelligible message, the Morse code (shown above) is used. Each letter is represented by a distinctive signal or group of signals, consisting of dots and dashes, or short and long sounds. On the recording instrument the dot and dash are indicated by deflections in opposite directions, these movements being caused by appropriate movements of the commutator at the sending station.

In a modern telegraph station, the signals are sent and received at high speed by apparatus which produces the message printed in ordinary type.

The telephone.—The telephone is an arrangement by which the sound of the human voice, or other sounds, may be reproduced over long distances. It consists of a transmitter or sending apparatus at

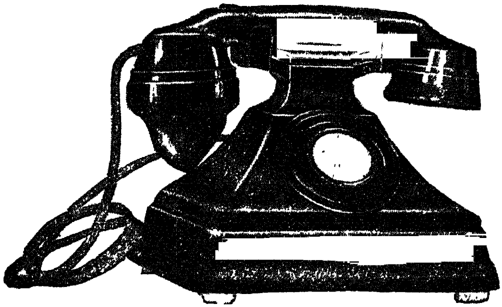


FIG. 190.—Combined transmitter (on left) and receiver (on right) of a modern telephone. In use, the handle connecting the transmitter and receiver is lifted from the support and the latter applied to the ear ; this brings the transmitter in front of the mouth.

one end, wires carried on poles or underground, and a receiver at the other end of the line.

In modern telephones the transmitter (see Fig. 190) consists of a mouthpiece so arranged that sounds produced in it cause vibrations of a sheet of aluminium to which is attached an aluminium cylinder with a plate of carbon on the end. The cylinder is inside a small box packed with small particles of carbon, the arrangement of which is disturbed by the vibrations of the aluminium diaphragm. As the current passes through the carbon by way of the line, the disturbance of the particles causes changes in the resistance to the current, which correspond with the vibrations of the carbon diaphragm. The rapid changes in the current so caused are carried through the line to the receiver.

The principle of the receiver, which was invented by Dr. Alexander Bell, is shown in Fig. 191. The chief part of the apparatus is a permanent horse-shoe magnet, upon the poles of which are fixed soft iron pole-pieces which almost touch a diaphragm *A*. Round these pole-pieces are wound many

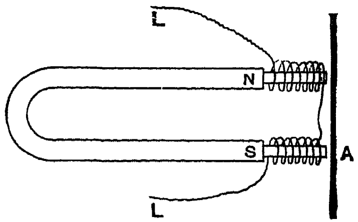


FIG. 191.—Principle of the Bell telephone.

turns of wire which form a part of the line *LL* in connection with the transmitter. As the varying currents pass through the coils on the pole-pieces of the receiver, they cause variations in the strength of the magnet and consequent variations in its attractive force for the iron diaphragm (*A*), which vibrates; its vibrations correspond with those of the diaphragm of the transmitter, and the same sounds are therefore reproduced.

For short distances the Bell telephone can also be used as a transmitter. The diaphragm is set in vibration by the sound-waves produced by the voice, and this causes minute varying electric currents (induced currents ; see p. 186) in the coils surrounding the magnet poles. If then the instrument be connected with another Bell telephone, these currents will cause the diaphragm of the latter to vibrate in the same way as the diaphragm of the transmitter, and the sounds spoken into the transmitter are thus reproduced.

Wireless telegraphy.—An electric spark, whether produced in the laboratory or as lightning, is not a single flash from one point to another, but a succession of very rapid " darts " of current or oscillations between the points. These oscillations give rise to waves which travel through space with the velocity of light ; they are, indeed, of the same character as the wave-motion of the light which affects human vision, but of a much greater wave-length. What may be called an " electric eye " is, therefore, required to perceive such rays ; and, with such a device it becomes possible to use these electro-magnetic waves for radio-communication.

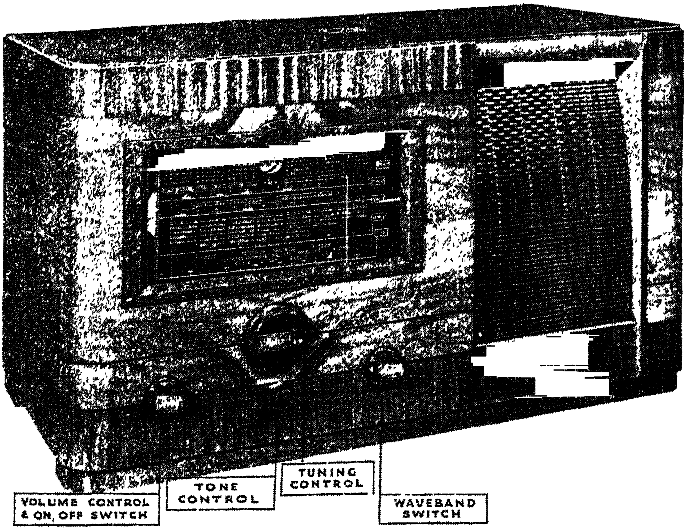
The " electric eye " used for detecting electro-magnetic waves is known as a **valve**. In appearance it is not unlike an electric lamp, but it contains, in addition to a filament, plates or wires connected to a small battery and to a telephone. The electro-magnetic waves passing through space meet the **aerial** set up at the receiving station and generate in it very feeble oscillating electric currents exactly similar to those causing the waves. The oscillations are so rapid, however, that a telephone would be unable to respond to them. The currents are therefore passed into the valve, the parts of which are so arranged that current passes *through* it in *one* direction only. By this means, half the oscillations are stopped, and the other half,

being all in one direction, have the effect of a single little pulse of current in one direction; the telephone can respond to a rapid series of such pulses, making a short buzz. By varying the duration of the spark or other generating impulse, it is possible to produce long and short buzzes and thus to use the Morse code.

Wireless telephony.—Many forms of "valve" are used in radio-communication. One form, referred to above, is used for detecting electro-magnetic radiations. Another form is used for producing continuous streams of electro-magnetic waves which can be radiated into space from an aerial, as distinct from the short or long pulses produced by an electric spark. In **wireless telephony** and in **broadcasting**, a continuous stream of waves of this character, known as a **carrier wave**, is sent out from the sending station. The carrier wave is thus named because it is made to *carry* slight modifications produced by the fluctuating current of a microphone. As in the ordinary telephone, the microphone picks up sound-waves produced by the voice, by music, or by other means, and translates them into a varying electric current. This varying current produces slight changes in the character of the carrier wave, which are reproduced in a receiving aerial. By suitable valves, these modifications are converted into electric currents, and, by yet more valves, magnified or *amplified* until they can be made to operate a telephone, in which are reproduced the sounds made at the sending station.

In broadcasting, it is often desired that many people shall hear musical programmes, talks, or news messages. For this purpose the telephone is replaced by a **loud-speaker**. These instruments are of various types, but all depend on the vibration of some form of diaphragm and are similar in principle to a telephone. By their use, it is possible for hundreds of people in a hall or in the open air to listen to the same programme.

Television.—A development of broadcasting is television, or the transmission of pictures and scenes. By the aid of a special form of "camera", an image of the scene is focused on to a "plate" which is electrically sensitive, and light and shade are translated, as it were, into varying electric currents, which are made to produce modifications on a carrier wave. At the receiving end, the original scene is

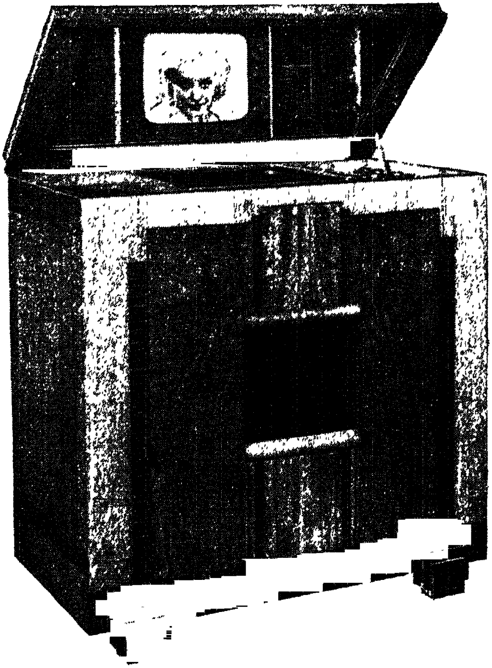


By courtesy of the Gramophone Company, Ltd.

FIG. 192.—A broadcast receiver, including the receiving equipment with various controls on the left, and loud-speaker behind the grille on the right.

built up on the flat end of a **cathode ray tube** by a very rapidly moving spot of light. Television sending and receiving apparatus does *not* deal with sound transmission, so two separate pieces of apparatus are required to " see and hear " a programme.

Radio-communication.—In ordinary telegraphy and telephony, the sender and receiver are connected by a wire or wires, and no one else receives the message. In radio-communication, the message or programme of music, etc., is sent out in all directions from the aerial of the generating station, and anyone with the necessary apparatus, suitably adjusted or **tuned**, can " listen in ". The range over which a station can be heard depends largely upon the amount of power it is radiating; and though in the case of the very short wave-lengths at present allotted to television, pictures are received at distances of sixty miles or so, the normal range of good reception is much less.



By courtesy of the Gramophone Company, Ltd.

FIG. 193.—A television receiver. The cathode ray tube on the end of which the picture is formed is inside the cabinet, and the picture is viewed in a mirror attached to the lid of the cabinet.

This universality of radio-communication has proved to be one of its most useful characteristics. A ship or an aeroplane, wherever it may be, can pick up or send out messages ; many lives have been saved at sea when vessels in distress have been able to notify other vessels of their exact position. Broadcasting has similarly been used to give urgent messages over a wide area. The more regular functions of broadcasting are to provide programmes of music or other entertainment, and to enable instructional and educational talks and news to reach everyone.

QUESTIONS ON PART I. PHYSICS

CHAPTERS I-II

1. Describe an experiment which shows that the pressure at a point in a liquid such as water depends on the depth of the point below the surface.

2. 100 c.c. of water is poured into a measuring cylinder A, and 50 c.c. into an exactly similar cylinder B. Compare the pressure on a water insect at the bottom of A with that on a similar insect at the bottom of B. (*Ans.* Pressure in A twice that in B).

3. How would you show by experiments (*a*) that an object such as a brass cylinder appears to weigh less when immersed in water than when hanging in air, (*b*) that when immersed in water it displaces a volume of water equal to its own volume.

4. State Archimedes' principle, and describe an experiment to prove it.

5. What conditions must be satisfied in order that a body may float partially immersed on the surface of a liquid?

6. A lump of copper weighs 120 grams in air; when suspended in water it weighs 106 gm. Calculate the weight of 1 c.c. of the copper. (*Ans.* 8·6 gm.).

7. A piece of iron sinks in water, yet an iron ship can remain afloat. Explain this.

8. Describe a hydrometer, and explain the principle of its use.

9. What do you consider to be the characteristic properties of liquids? Describe and explain how a liquid is utilised in a surveyor's level.

10. Explain how a fountain works.

11. Define the density of a substance. A cube of lead, the side of which measures 2 cm., weighs 91·22 gm. Calculate its density. (*Ans.* 11·40 gm. per c.c.).

12. A small measuring cylinder is weighed before and after pouring exactly 5 c.c. of turpentine into it. The difference of weight is 4·34 gm. What is the density of turpentine? (*Ans.* 0·87 gm. per c.c.).

13. What is specific gravity? Describe how you would find the specific gravity of brine with a specific gravity bottle.

14. You are given a packet of iron nails and a specific gravity bottle. How would you find the specific gravity of the iron of which the nails are made?

15. How would you make use of the Principle of Archimedes to determine the specific gravity of a lead bullet?

16. A vase is said to be solid gold, the specific gravity of which is 19·3. Its weight in air is 27 gm. and its weight in water is 24·7 gm. Is it gold or lead with a gilded surface? (Specific gravity of lead is 11·4.) (*Ans.* Gilded lead).

Chapters III-IV

17. Describe two simple experiments which show that the atmosphere exerts pressure in all directions.

18. Why is it that when a glass tube is passed through a rubber cork fitting a flask containing water, it is not possible to suck out the water although the tube dips into it?

19. What instrument is used to measure atmospheric pressure? How would you construct a simple instrument of this kind?

20. Describe the principle on which the aneroid barometer works. How does it differ from the standard barometer?

21. Why is mercury used in a barometer instead of water? What would be the height of a water barometer at sea-level?

22. State Boyle's Law and describe an experiment illustrating it.

23. The volume of air in a stout glass tube closed at one end is 112 c.c. A tightly fitting plug is pushed slowly into the tube until the air is compressed to 28 c.c. If the temperature has remained constant and the atmospheric pressure is equivalent to 75·6 cm. of mercury per sq. cm., calculate the pressure in centimetres of mercury necessary to do this? (*Ans.* 302·4 cm. of mercury).

24. Describe how the suction pump works, drawing diagrams to illustrate the action.

25. How is air forced into a pneumatic tyre? Describe with a diagram the apparatus used.

26. Describe, with a sketch, how a primus stove works.

27. Explain the action of the siphon. What is the greatest height over which it would be possible to carry mercury by means of a siphon?

Chapters V-VII

28. What experiments would you make in order to show that (*a*) iron, (*b*) water, (*c*) air expands on heating?

29. Compare the effects of heat on the volume of solids, liquids and gases.

30. Explain what is meant by temperature, and describe the Fahrenheit and centigrade scales of temperature.

31. What is the difference between a mercury and a spirit thermometer? Mention the particular advantages of each.

32. Write down the freezing point and boiling point of water at atmospheric pressure on the Fahrenheit and centigrade scales. If you observe that the temperature of the laboratory is 21·5° C., express this as degrees Fahrenheit. (*Ans.* 70·7° F.).

33. The temperatures in three rooms, *A*, *B*, and *C*, of a house are 67° F., 24·8° C. and 72·5° F. respectively. Which is the coolest, and which is the hottest room? (*Ans. A* coolest, *B* hottest).

34. Describe some industrial applications in which allowance has to be made for the expansion of iron.

35. Describe the mercurial pendulum. Why is this form of the pendulum used?

36. Draw a diagram to show roughly the kind of changes in volume undergone by water as the temperature falls from + 10° C. to − 10° C. Discuss any important phenomena which your diagram illustrates.

37. What do you mean by the phrase "conduction of heat"? Metals are said to be good conductors of heat. Describe two simple experiments which show this?

38. How is heat transmitted through a liquid? Describe an experiment to demonstrate the process.

39. How does radiation of heat differ from conduction and convection?

40. Describe the thermos or vacuum flask.

41. Why is a glass chimney used on a paraffin lamp? How is convection of heat concerned?

42. What part does convection of heat play in the ventilation of a room?

43. Discuss the importance of convection currents in air as factors affecting the climate of a country.

44. The air contains water vapour. Describe the formation of (*a*) rain, (*b*) snow and (*c*) hail.

45. How would you compare the radiating power of surfaces of different types? Contrast this mode of transmission of heat with (*a*) conduction, (*b*) convection.

46. Describe some ways in which use is made of the different radiating and absorbing powers of various substances.

47. Distinguish between quantity of heat and temperature.

48. How does temperature in the study of heat resemble and differ from level in the study of liquids?

49. Define a calorie. What quantity of heat is required to heat 52 gm. f water from 22° to the boiling point (100° C.)? (*Ans.* 4056 calories).

50. How many units of heat are required to heat 43 gm. of water rom 18° C. to boiling point (100° C.)? If this water be poured into 0 gm. of water still at 18° C., what will be the temperature of the nixture? (*Ans.* 3526 calories, 78·6° C.).

51. How is the high capacity of water for heat concerned in the pro-luction of sea- and land-breezes?

52. What is meant by "specific heat"? Two beakers of the same ize and material contain *equal* amounts of water at the room tempera-ure. Into one of them a certain mass of hot water is poured, and into he other an *equal* mass of iron, heated to the same temperature as the ot water, is introduced. Which will give the higher resulting tempera-ure, and why?

53. Define latent heat. When a few drops of methylated spirit are oured on the hand, the liquid quickly evaporates, leaving the hand eeling very cold. Explain this.

54. Explain what is meant by the statement that "the latent heat f fusion of ice is 80 units of heat". A kilogram of ice at - 10° C. is eated until the whole evaporates. How much heat is required? Latent heat of steam is 540 units of heat.) (*Ans.* 820,000 calories).

55. How does the boiling point of a liquid depend on the pressure?

56. Describe the changes that take place when a flask, partly filled vith water, is heated on a sand bath until the water boils. Under what onditions does water boil (*a*) at 100° C., (*b*) below 100° C.?

CHAPTERS VIII-IX

57. What do you mean by (*a*) potential energy, (*b*) kinetic energy? Give examples of both.

58. Describe the spring balance. A small cube of metal is weighed n a spring balance and on a chemical balance at a station high up on mountain. Would the weights shown be the same?

59. What is meant by friction? Describe and explain one example each n which (*a*) friction is used, (*b*) friction is reduced as much as possible.

60. Define the term "work". How much work is done when a oaded truck, which requires an effort of 2 cwt. to move it, is pushed alf a mile? (*Ans.* 591,360 ft. lb.).

61. State the principle of the lever. What will be the effect on the veighing if the arms of the balance are not equal in length?

62. Draw diagrams, marking in each case the fulcrum, effort and oads, showing three ways of using a lever.

63. Name some household articles in which the principle of the lever s used. Name the fulcrum, effort and load in each case.

64. What do you mean by the "principle of work"? An iron bar is resting horizontally; a load of 500 lb. weight hangs at one end, at a distance of 1 ft. from the point of support. What effort is being applied at a distance of 4 ft. on the other side of the point of support to keep the bar stationary? If the load moves down 1 in., how far does the effort move? (*Ans.* 125 lb. weight; 4 in. up).

65. Define "mechanical advantage". By means of a lever, a load of 200 lb. weight is lifted by a man exerting a force of 10 lb. weight. What is the mechanical advantage obtained? (*Ans.* 20).

66. State the principle of the action of a simple pulley. Explain, with the aid of diagrams, how pulleys can be used to open and close a curtain hanging before a doorway.

67. Describe a pulley system consisting of two blocks, one containing two wheels and the other one wheel. What is the mechanical advantage of using these pulleys, if friction is neglected? (*Ans.* 3).

68. Why is mechanical advantage obtained by using an inclined plane?

69. A loaded truck weighing 5 cwt. has to be pulled on to a platform 2 ft. high. Planks 6 ft. long are arranged as an inclined plane against the platform. What effort would be required to drag the truck on to the platform? (*Ans.* 186·6 lb. weight).

70. What use is made of the principle of the inclined plane in constructing roads and railways?

71. Why are springs fitted to carts? Describe a simple cart spring.

Chapters X-XI

72. A metre scale at each end of which a 50 gm. weight is hung, is hung by a loop of thin wire to the hook of a spring balance. At what point on the scale will the wire hoop be when the scale balances horizontally? What weight will the spring balance register if the scale weighs 62 gm.? What principle does this illustrate?

(*Ans.* 50 cm.; 162 gm.)

73. You are supplied with two spring balances each reading in ounces up to 7 lb. only, together with a brass rod. Describe a method by which you could find the *correct* weight of a parcel weighing about 9 lb.

74. Define the centre of gravity of a body. The centre of gravity of boxwood metre scale, which has some holes bored in it, is at the 49 cm mark. Being supplied with a 50-gm. weight, and using the scale as lever, describe how you can determine its weight.

75. Describe one method of finding the centre of gravity of a fla sheet of cardboard of irregular shape.

76. What do you mean by the "three states of equilibrium"?

77. Describe the state of equilibrium of (*a*) a ball resting on a horizontal table, (*b*) an electric light globe hanging from a ceiling, (*c*) a bottle lying on its side on the ground, and (*d*) a thin stick held vertically by the lower end. Give reasons for your answers.

78. A lamp for use on a table is generally made with a heavy base of large area? Why is this done?

79. A conical flask such as is used in chemical work is less easily upset than an ordinary flask. Why is this?

80. Explain (*a*) why a man walking a tight-rope usually carries a long pole, (*b*) why ballast is loaded into a cargo vessel if she has to go to sea without a cargo of merchandise.

81. Describe a simple pendulum. What is meant by its " period "? How is this affected by changes of temperature?

82. What is the standard unit of time and what is meant by a seconds' pendulum? Describe experiments you have performed to find how the period of a simple pendulum depends on its length.

83. Give an account of a simple form of steam-engine, illustrating your answer with a diagram.

84. Describe, with diagrams, the working of *any* engine, emphasising the part played by the flywheel and the valves.

85. Indicate the transformations of energy which take place when a steam engine is driven by means of a boiler heated by a coal fire. Explain with the help of a diagram how the piston moves in the cylinder of a steam engine.

86. What is meant by an internal combustion engine? Describe, with a diagram, a simple gas engine.

87. What is the characteristic feature of a Diesel engine? Where are such engines commonly used?

88. Describe how belts and gears are used to transmit power from an engine to the place where it is required.

89. What do you mean by the conservation of energy? Mention *three* kinds of energy widely used by man.

Chapter XII

90. Describe an experiment showing that sound is transmitted through the air.

91. When a tuning fork is struck, a humming note is heard. Describe how the sound is produced and transmitted to the ears.

92. Describe the principal organs concerned in producing the human voice.

93. Explain the production of an *echo*. During a fog the officers of a ship near a shore bounded by high cliffs hear an echo of the ship's

fog-horn 4 seconds after the fog-horn has stopped. How far is the ship from the cliffs? (Velocity of sound in air, 1100 ft. per sec.)

(*Ans.* 2200 ft.).

94. Describe how the gramophone reproduces music and other sounds.

Chapters XIII-XV

95. Describe a simple experiment you would carry out to show that light travels in straight lines.

96. Describe, with diagrams, the differences, if any, between the shadow of a rod when the source of light is (*a*) broad, (*b*) narrow.

97. Draw diagrams to illustrate how a partial and a total eclipse of the moon are produced.

98. Describe a simple form of pinhole camera. Draw a diagram to show how it is that an inverted image is formed.

99. State and explain the laws of reflection. Describe a simple experiment to prove them.

100. A plane mirror is held in a clamp attached to a retort stand so that its surface makes an angle of 45° with the horizontal. Another plane mirror is held vertically above the first with its surface parallel to and facing the first mirror. Draw a diagram showing how a horizontal ray of light will be reflected by the arrangement.

101. What is meant by (*a*) radius of curvature, (*b*) principal axis, and (*c*) principal focus, of a concave mirror?

102. Why does the back of a motor-car head lamp often consist of a concave mirror? Where is the source of light placed with regard to this mirror?

103. Give an account of an experiment which you have performed or witnessed relating to refraction of light. State clearly what you learnt from the experiment regarding the laws of refraction.

104. A coin lying on the bottom of a sink full of water is just visible when you are sitting near by. If some one takes the plug out of the sink, so that the water runs out, the coin is no longer visible unless you move nearer the sink. Explain this.

105. Why does a straight stick, part of which is dipping into a bowl of water, look as if it was bent?

106. Sketch the path of a ray of light when it passes through a glass prism. Explain why objects seen in ordinary sunlight through a glass prism appear to be displaced.

107. What is the effect of passing a beam of white light through a glass prism? Draw a diagram illustrating your answer.

108. What do you mean by a converging lens? Define (*a*) principal focus, (*b*) axis of a lens.

109. A converging lens is sometimes used as a magnifying glass. Show, with a sketch, how an enlarged image is formed.

110. Describe, with a sketch, the principle of the photographic camera.

111. It is sometimes said that the eye is like a camera. Describe features of the eye in which it is like the camera.

112. Describe how a magic lantern is used to produce a large picture on a class-room screen.

113. Describe the principle of the astronomical telescope of moderate size.

114. How does (*a*) an epidiascope, and (*b*) a cinematograph machine differ from a magic lantern?

Chapters XVI-XVII

115. A bar magnet is suspended by fine thread. What would be the effect of bringing near the ends in turn (*a*) a large iron nail, (*b*) another bar magnet?

116. Explain the statement: "Repulsion is a surer test of magnetism than attraction."

117. Draw a sketch of the magnetic field around a bar magnet.

118. Two bar magnets are arranged 1 inch apart and parallel to each other with opposite poles facing on a sheet of paper. Iron filings are sprinkled on the paper. Sketch the magnetic field thus shown.

119. When a magnet is suspended by a thread, it comes to rest pointing north and south. What explanation can be given of this?

120. What do you mean by (*a*) magnetic dip, (*b*) declination?

121. Describe a magnetic compass and explain its uses.

122. Describe some experiments showing the effects of magnetic induction.

123. Describe how you would magnetise a knitting needle. How would you prove that the needle had become magnetised?

124. A small piece of cork is suspended from a stand and a piece of rubbed sealing wax is brought near it. Describe what happens? If the cork touches the wax, does the effect change?

125. How can you show experimentally that there are two kinds of electrification?

126. It is stated that during electrification equal and opposite charges are produced. What experiment have you seen which supports this statement?

Chapters XVIII-XX

127. Describe a simple voltaic cell. What happens when the metal rods used in such a cell are connected by a wire outside the cell?

128. What do you understand by electrical potential?

129. Why is a simple voltaic cell not suitable as source of a steady electric current?

130. What means are adopted to overcome polarisation in (*a*) a Bunsen cell, (*b*) a Daniell cell, (*c*) a dry cell?

131. How would you test an accumulator to discover if it was charged? Describe the chemical reactions taking place in the cell.

132. Describe an experiment to show that an electric current produces magnetic effect. A wire is wound into a coil and a current of electricity is made to flow through it. How would you find out which end of this coil behaves like the north pole of a magnet?

133. How would you make an electro-magnet?

134. Describe how to make a simple form of galvanometer. What is such an instrument used for, and how can it be made more sensitive?

135. What is Ampère's rule?

136. Explain what is meant by the resistance of an electric current. How does resistance depend on the length and thickness of a conductor, and the material of which it is made?

137. Describe the construction of an electric filament lamp.

138. Describe three forms of electric lighting in common use.

139. Explain the working of an electric bell, and show why an electro-magnet is employed in its construction.

140. Explain what is meant by an induced current. Describe an experiment to show the production of such a current.

141. Explain the principle of the dynamo.

142. What is the difference between a dynamo and an electric motor?

143. What do you understand by "electrolysis"? How would you set up an experiment to show the electrolysis of water?

144. Why is a fuse inserted in an electric circuit?

145. Describe, with a diagram, a simple form of telegraph circuit.

146. Draw a rough sketch of a telephone transmitter and describe how it works.

147. Describe the principle of the telephone receiver.

148. In "broadcasting", speech and music are transmitted over a distance by electromagnetic radiations. Describe, in outline, how this is done.

PART II

CHEMISTRY

CHAPTER XXI

SOLUTION. FILTRATION. DISTILLATION

Solution.—When sugar is placed in water it disappears, but it is not lost, for it can be tasted in the water. It is said to have **dissolved** and formed a **solution** of sugar. A great number of substances can dissolve, or are soluble, in water, but not all to the same extent; and when, at a given temperature, no more of the substance can be dissolved, the solution is said to be **saturated**. A dissolved substance is known as a **solute**, and the substance in which it is dissolved is called a **solvent**.

By heating a solution in a suitable vessel, the water is driven off in the form of water vapour, and the substance dissolved in it is left behind in the vessel and may be recovered without loss. Hence, during ordinary solution there is no chemical change, but merely a change of physical state. However, in certain cases solution may be accompanied by chemical changes.

Many things besides sugar are soluble in water. Washing-soda, salt, borax and nitre (saltpetre) easily dissolve. Many other things will not dissolve in water, and these are then said to be **insoluble** substances. Among substances insoluble in water are sand, glass, coal, camphor and sulphur. But camphor dissolves in alcohol, and sulphur in carbon disulphide. Thus although it is generally understood that water is the solvent when it is stated that a substance is soluble or insoluble, it is more correct to state the solvent when these terms are used.

Solution and temperature.—Though there are exceptions, it is the general rule that water and other liquids will dissolve more of a solid when they are warm than when they are cold. In some cases the amount of solid which will dissolve goes on increasing as the

water is made warmer. In general, the cooler the water the less will it dissolve of a solid. If, therefore, warm water is given as much sugar, alum, or any substance of this kind as it will hold, and is then cooled, it has to give up some of the substance, for it cannot hold as much as when it was warm. Salt is peculiar in that hot water dissolves only a very small quantity more than cold water. When stating the solubility of a substance in water (actually the amount required to produce a saturated solution with 100 gm. of water), it is therefore necessary to give the temperature at which the solubility is measured.

Water as a solvent.—Water dissolves more solids than any other liquid which is known. It is such a good solvent that it is impossible to find pure water anywhere in nature—that is, in any stream or lake in any country. Water will not only dissolve solids, but also liquids and gases as well. As soon as rain is formed from a cloud, it begins to dissolve some of the gases of the atmosphere, and no sooner has it reached the earth than it dissolves things out of the ground. Of those substances in the soil and rocks which are soluble it dissolves a great deal, while of the so-called insoluble things, such as chalk, it dissolves a small amount, for few things are absolutely insoluble.

The solvent power of water is very important in life processes. Plants take in most of the raw material they need for building up their tissues in the form of very dilute solutions, while the solid food consumed by animals is largely broken up in their intestines, so from it can pass, in solution, into the blood stream and so be utilised in the animal body.

Evaporation.—By gently warming water or other liquid, or even by allowing it to remain exposed to the air for some time, the liquid passes off as vapour without actually boiling. Rain drops on window panes disappear by reason of this process, which is called **evaporation.** Similarly, a dish of water " dries up " by evaporation of the water. Any dissolved substance remains behind, forming a residue.

Distillation.—By the evaporation of the solution, the liquid in which the substance is dissolved can be separated from the dissolved

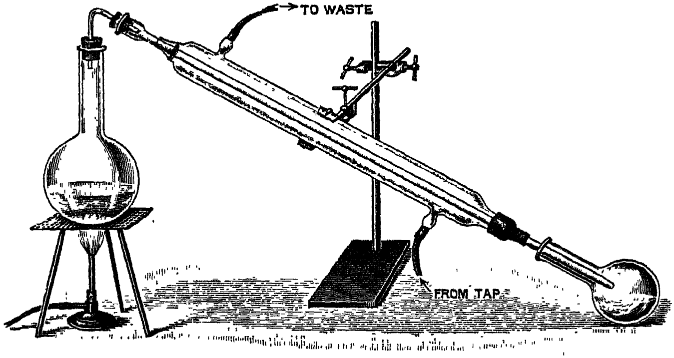


FIG. 194.—Distillation of water.

substance, and this process is used not only for obtaining the dissolved substance, but also for the purification of liquids from dissolved solid materials. If the steam, formed by boiling water containing dissolved substances, be cooled in some way—that is, condensed—the water formed is quite pure. To obtain pure water from impure water, it is boiled, and the steam which is given off is condensed. Any dissolved materials are left behind in the vessel in which the boiling takes place Apparatus which can be used for this purpose in the laboratory is shown in Fig. 194.

Thus drinking water can be obtained if required from sea-water, but such distilled water is not pleasant to drink ; it contains little dissolved air and tastes " flat ". Impure water will cause corrosion and also leave deposits in boilers, which interfere with the heating of the water in them. In big steam engines the waste steam, or exhaust, is therefore condensed and pumped back to the boilers again ; in this way pure water is continually being returned to the boilers. There is a constant circulation of the same water and very little additional water is required, except for the condensation of the exhaust steam.

Filtration.—When a muddy liquid, containing solid particles suspended in it, is poured on filter paper, the solid particles remain on the paper while the clear liquid passes through. This process is

called **filtration**, and it is adopted when it is required to separate insoluble suspended material from a liquid, either to obtain the solid separately or for the purification of the liquid. The clear liquid, which passes through the filter paper and is collected below in a flask (Fig. 195), is called the **filtrate**, and the insoluble substance left on the filter paper in the funnel is called the **residue.**

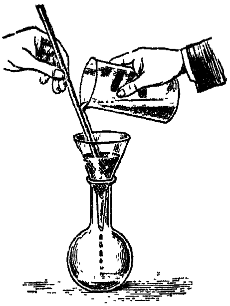


FIG. 195.—Filtration and decantation.

Other substances besides unglazed paper are sometimes used in filtering. Thus the water supply of a town is often filtered through beds of sand. Household filters are made with pieces of charcoal for the water to trickle through, and in some others a particular kind of porous iron or porcelain is employed. Every filter requires to be cleaned frequently, because it gets clogged with impurities from the water which has filtered through it.

Decantation.—If an insoluble powder be stirred up with water, it may be separated partially from the water by allowing the mixture to stand and settle for a while. With care the clear liquid may be poured off from the sediment, and this process is known as **decantation** (Fig. 195). As, however, it is impossible to remove the whole of the liquid in this way, filtration is the method usually employed.

Formation of crystals.—Most substances dissolve more readily in hot than in cold water—that is, the solvent power of water increases with the temperature. A hot saturated solution contains more of the solute than a cold one ; when the hot solution is cooled, some of the dissolved substance separates out as **crystals**, and this is known as **crystallisation.**

Crystallisation occurs when a dissolved solid separates from its solution, either by cooling the solution or by the evaporation of the solvent ; and the more gradual the cooling, or the slower the evaporation, the larger and more perfect are the crystals obtained. Crystals may be formed during the solidification of a melted solid, especially when it is allowed to cool and to solidifv slowlv.

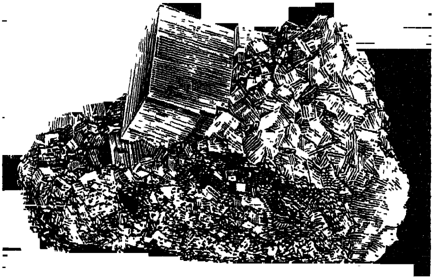


FIG. 196.—A natural crystal of common salt. Notice the cubical shape.

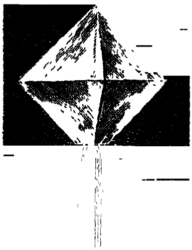


FIG. 197.—A crystal of alum.

Every substance capable of crystallising forms crystals of a definite shape. Thus, common salt crystals have the shape of *cubes* (Fig. 196), alum that of *octohedra* (Fig. 197), each of which appears to be made from two equal square pyramids placed base to base. Other shapes are much more difficult to describe, but crystals, in general, have shining faces and sharp edges.

Other solvents.—The fact that other liquids besides water will dissolve substances is of great value in examining the properties of bodies. Water, though the commonest and most useful solvent, will not dissolve some substances which are readily soluble in other liquids. Though camphor is insoluble in water, it is soluble in alcohol; a solution of camphor in alcohol can be made. Shellac is another substance which will dissolve in alcohol and not in water; such a solution, in fact, makes a varnish used for covering some kinds of furniture. Sulphur, again, though it will not dissolve in water, and only very little in alcohol, disappears very quickly if placed in the liquid called carbon disulphide. In each of these cases the dissolved body can be recovered by evaporation of the solvent, and a **physical change** is said to have occurred.

Chalk will not dissolve in water, but it will dissolve in a weak acid, such, for example, as vinegar; in this case the chalk cannot be recovered by evaporation of the solvent, so a **chemical change** is said to have occurred.

Solution of one liquid in another.—The commonest examples of solution are when solid substances are dissolved in liquids. In addition to this, many liquids will dissolve in other liquids. Alcohol and glycerin are examples of liquids which will dissolve in water. Many oils and also grease will dissolve in petrol, which can thus be used to remove grease stains from clothing.

PRACTICAL WORK

1. **Solution.**—Place a piece of sugar in water and note that it soon disappears and gives a sweet taste to the whole of the water; hence the particles of sugar must be spread through the entire mass of the water.

2. **Saturated solution.**—Weigh out 10 grams each of the following substances: powdered nitre, salt, washing-soda, copper sulphate; to each add water in small quantities, with vigorous shaking after each addition. Determine thus the quantity of water necessary to form a saturated solution of each—that is, a solution in which no more of the solid will dissolve.

3. **Evaporation.**—Weigh out a quantity of salt in an evaporating basin and add water to dissolve the salt. Stand the basin in a tin dish of sand, and heat the dish gently over a Bunsen burner so that the water boils and evaporates away completely. A white solid remains in the basin; weigh the evaporating basin and residue when cool. Note that the weight is practically equal to the weight of the basin and salt before solution; taste the solid left in the basin.

4. **Distillation.**—(*a*) An arrangement for condensing steam or vapour is shown in Fig. 194. Some salt solution is boiled in a flask, and the steam that comes off passes through a long tube passing through an outer tube in which cold water from the tap is running; the steam is thus condensed as pure water.

The last experiment may be repeated with methylated spirit instead of water. The flask should this time be heated on a water-bath.

(*b*) Evaporate gently a little distilled water from the last experiment in an evaporating dish. Notice the absence of any residue. Repeat the experiment with a larger amount of ordinary water, and note the residue.

5. **Filtration.**—Make some water turbid by adding mud or powdered chalk to it. Take a circular piece of filter paper and fold it in two in the form of a semicircle, then again to the form of a quadrant (Fig. 198, *a*, *b*, *c*); open the paper out into the form of a hollow cone and fit it into a glass funnel (Fig. 198, *d*, *e*). Pour the muddy liquid into this filter and note that the water runs through perfectly clear, leaving the insoluble matter in the filter paper.

6. **Solubility of various substances.**—Take small quantities of powdered chalk, alum, lime and soda; add a few c.c. of distilled water to

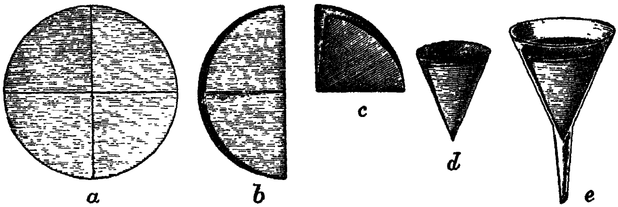


FIG. 198.—How to fold a round piece of blotting paper for filtering.

each in a boiling tube and heat. Filter from any undissolved matter and evaporate the filtrate. Hence find which substances are soluble in water.

7. **Solubility in water.**—Place a quantity of powdered nitre in water and allow it to stand for some time with frequent vigorous shaking, so that a cold saturated solution is formed. Take the temperature of the water. Measure 20 c.c. of this solution into a small weighed evaporating dish. Evaporate to dryness, allow to cool, and weigh the residue. Warm 20 c.c. of the solution to 30° C. and add more nitre until it is again saturated. Keep the temperature at 30° C. all the time. Find the weight of nitre in 20 c.c. of solution. Repeat this for as many temperatures as possible up to 50° C. Repeat the whole experiment using common salt instead of nitre. In order to make sure that the solutions obtained are saturated, there should always be a little *undissolved solid* left in the solution.

8. **Crystals.**—Allow the remainder of the hot saturated solution of nitre or salt obtained as above to cool slowly, and observe that the dissolved solid separates out from the solution as clear glassy pieces, which increase in size as the solution cools. Examine a few of these and see that they are bounded by plane surfaces.

9. **Various solvents.**—(*a*) Satisfy yourself that camphor, shellac, sulphur and chalk are insoluble in water.

(*b*) Now try to dissolve the camphor and shellac in alcohol, the powdered sulphur in carbon disulphide,* and the chalk in a weak acid such as vinegar. Note that in each case a solution is readily formed. Observe that solubility in different solvents provides a further means of distinguishing between substances.

10. **Solution of liquids.**—(*a*) Pour some water into a bottle and then some alcohol and shake them up together. Observe that the alcohol disappears in the water or dissolves in it.

(*b*) Shake up together some olive oil, water and mercury, and allow the mixture to stand for a short time. Notice that the liquids separate into layers, the lightest being at the top. Which is the lightest?

* On no account should the carbon disulphide be heated or brought near a flame; the sulphur must be dissolved by shaking.

CHAPTER XXII

BURNING AND RUSTING

Some substances will burn in the air.—Substances which burn in the air are said to be combustible. The burning of ordinary combustible substances, such as paper and wood, provides examples of chemical change. After burning, they seem to have disappeared or almost disappeared. At first a black, charred residue is left; but with a rise of temperature the residue glows for a time, and eventually only a little grey ash remains. Clearly the original substances are not the same as the smoke and ash formed as the result of burning.

When sulphur is heated in the air, it first melts into an amber-coloured liquid. Soon the vapour given off catches fire and the sulphur burns with a light blue flame. A strong odour of "burning sulphur" is noticed. The whole of the sulphur burns away, and apparently disappears; but the strong smell of burning sulphur suggests that a new substance in the form of a gas has been formed. The burning of sulphur is another example of chemical change.

These changes only take place when the heated substances are in contact with air. Substances such as wood, when heated without air, undergo changes and are partially decomposed; but complete combustion accompanied by flame only takes place when air is present.

Changes in ordinary burning.—Numerous common substances when heated give off smoke, being changed first into a black, charred residue; when the heating is continued and the temperature increased, this residue disappears, provided that air is present, leaving a small amount of ash. When wood is heated in a tube held in a flame (Fig. 199), moisture is deposited on the cool part of the tube and a gas is given off which will burn.

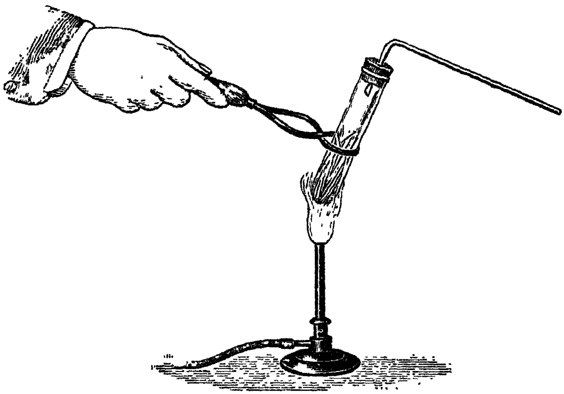


FIG. 199.—Heating wood in a hard glass tube.

A candle will not continue to burn very long in an enclosed quantity of air. Unless the air is renewed the candle flame goes out. This gives a convenient starting point for the inquiry, Why does the candle flame go out, and what changes take place while the candle is burning?

When a dry glass or jar is held over a burning candle (Fig. 200), drops of liquid begin to collect on the inside of the glass, and after a time they run down the sides. The burning of a candle thus causes a liquid to be produced. If enough of this liquid is collected, it can be proved to be water by tasting it, or by determining its density, or its boiling and freezing points. Water is the only liquid which boils at 100° C. and freezes at 0° C., and the density of which is 1 gram per cubic centimetre.

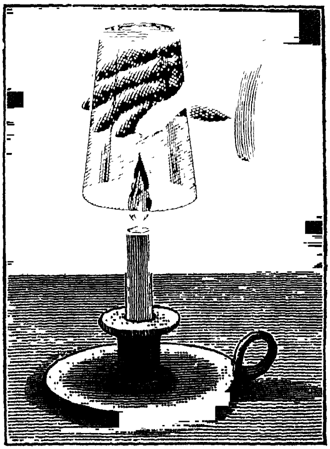


FIG. 200.—To show the formation of moisture by the burning of a candle.

The gas which is left behind when a candle is made to burn in a glass jar can be examined. Experiments with this gas show that it will not allow things to burn in it. Also, the gas turns lime-water milky.

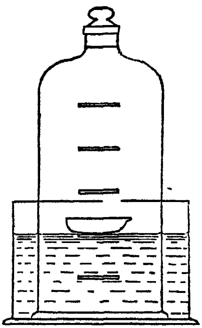


FIG. 201.—Phosphorus uses up one-fifth of the air in the bottle when it burns, and water rises to take the place of the air used.

Phosphorus readily burns in the air.—It is only necessary to touch a piece of dry phosphorus with a hot wire to make it catch fire and burn. It burns with a dazzling bright flame and with the formation of dense white fumes until all the phosphorus has disappeared.

When phosphorus is burned in air enclosed in a bell-jar standing mouth downwards in water, then after the fumes have settled and dissolved, the water is seen to have risen in the jar, indicating that there is less gas in the jar than before the phosphorus was burnt (Fig. 201). Further, the gas left in the jar will not allow a taper to burn in it.

The fraction of the air which disappears as a result of the burning of the phosphorus can be measured if the bell-jar has been marked as in Fig. 201. On starting the experiment, the water-lèvel inside and outside the jar is adjusted to the lowest mark. The phosphorus is ignited by a hot wire, the stopper inserted, and when the action is finished and all is cool, the water-level in the dish is made level with that inside the bell-jar. It is then found that the water-level is at the second mark.

Hence phosphorus burning in air removes an active portion, one-fifth of the whole in volume, and leaves an inactive residual gas which occupies four-fifths of the original volume. A burning candle similarly removes the active fraction of the air, leaving the inactive residue which will not support combustion.

When a piece of clean phosphorus is exposed to an enclosed quantity of air over water, the rapid changes just described take place slowly. The only difference is the rate at which the active part of the air is taken out. Burning phosphorus combines with the active part very quickly ; cold phosphorus but slowly.

A change such as this, in which the same products are formed as in actual burning, is sometimes known as **slow combustion.**

Action of heat on metals.—Different metals are affected by heat in various ways.

Iron, in the form of steel, has its temperature raised steadily when heated, but it cannot be melted by ordinary fires or laboratory flames. If clean iron filings are heated, the shiny metal will become black, due to the formation of a thin black film on the particles.

When **copper** is heated in contact with the air, a black film is formed on the surface of the metal, a fact which leads to the conclusion that though the metal does not melt, yet a chemical change takes place.

Tin melts into a silvery fluid, which can be cast in moulds easily. If the molten metal be kept stirred with an iron wire, it is changed quickly into a *scum,* which is at first grey; but with strong heating a yellowish powder may be formed which is white when cold.

Zinc, too, melts easily when heated in a crucible. When the air can get freely to the melted zinc, a new compound is formed by the zinc combining with something out of the air. The new compound is a powder which is white in colour when cold, but yellow when hot.

When **magnesium** is heated in air, it at once catches fire and burns brilliantly, giving an intense light. Like zinc and lead, the magnesium forms a new compound—a white powder—by uniting with something out of the air.

It has already been seen that, by heat, solids may be melted to form liquids, and liquids converted into vapours. If a piece of platinum wire be held in the flame of a laboratory burner it becomes red hot; but when it is taken out of the flame it quickly resumes its ordinary colour, and no change can be seen. Paper and wood when heated strongly in air take fire and burn; smoke is given off, and an ash remains. Metals like copper become covered with a film, or tarnish, when they are heated in air. Tin and zinc when strongly heated melt and become covered with a scum on the surface. Like magnesium, these metals gain in weight.

If metals are heated in closed tubes without air, they do not change in this way. It thus seems that the tarnish is due to the absorption

of something from the air. But if something is taken from the air when a metal tarnishes, or when a metal like magnesium burns, the tarnished metal, or the ash of the magnesium, should weigh more than the original substance. Careful weighing shows that this is actually so.

Chemical properties of air.—It is necessary carefully to consider the changes which some substances undergo when simply exposed to the atmosphere, and other changes when they are *heated* in the air. It is best to begin with the simplest cases. When iron is exposed to damp air it becomes rusty. Does the iron give up something when it rusts? Or does it gain something?

Iron gains in weight during rusting.—If a known weight of iron be allowed to rust by contact with damp air, the weight of the iron after the rusting has taken place is greater. The result of this experiment is important. The substance causing the increase of weight, when damp iron filings rust, could come from the water or moisture, or from the air. If the iron be allowed to rust in a closed space, so that if anything is taken from the air the loss can be detected, it can be decided whether the air causes the rusting.

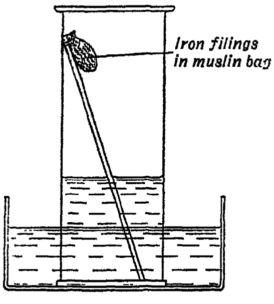


Fig. 202.—Experiment to show the action of iron filings on air.

Fig. 202 shows a way of doing this. Some iron filings are placed in a muslin bag, and the bag is tied to a piece of glass rod. The bag of filings is moistened, and arranged in a bottle of air inverted over water in a basin. The apparatus is then left undisturbed for a day or two. When it is examined, the water is seen to have risen in the bottle. It is clear that there is less air in the bottle now than there was before the iron became rusty. Some part of the air has, therefore, been used by the iron as it rusted, and this part of the air has joined with the iron to help to make the rust.

What fraction of the air is used by iron in rusting?—Only a certain fraction of the enclosed air is taken up when iron rusts in it. The

amount of water which rises into the bottle can be measured. As this water takes the place of the part of the air which the iron uses, its volume must be the same as the volume of the gas so taken out of the air. The amount of water the bottle holds when full can be found, and the result shows the volume of air originally in the bottle.

It will be found that when the bottle is full of water, it holds five times as much water as it contained after the iron had rusted. If the experiment is repeated several times with bottles of different sizes, the result is the same. It is always found that **one-fifth of the volume of the enclosed air is used up by iron in rusting.**

Air, as well as iron, undergoes change.—When iron rusts, the change which it has undergone is visible. The air left in the bottle, however, *looks* the same as ordinary air. But there is a great difference. A lighted taper is extinguished by the gas left in a bottle ; hence the gas cannot be air, for in air a taper will burn. But, before the rusting of the iron took place in it, the gas *was* ordinary air. Hence the rusting of the iron is accompanied by a change in the character of the air. The gas which disappears, therefore, is concerned in the formation of iron rust, just as it is concerned in the burning of phosphorus. When iron rusts, it takes out of the air an active part which helps burning, and, moreover, the iron and the part of the air concerned in burning combine together to form iron rust. The part of the air left in the bottle will not let things burn in it. It may therefore be stated that: **Iron in rusting gains in weight, taking some material from the air, and this material is the part of the air which causes substances to burn in it.**

Chemical composition of the air.—It has now been shown that the rusting of iron causes precisely the same change in the air as the burning of phosphorus. The results of both sets of experiments show that air is made up of 1 volume of the active part to 4 volumes of the inactive part, in every 5 volumes. In other words, in 100 litres of air there are 20 litres of gas which will unite with iron to make iron rust, or will assist a candle or phosphorus and other things, such as carbon and magnesium, to burn, and 80 litres of the inactive part in which nothing will burn.

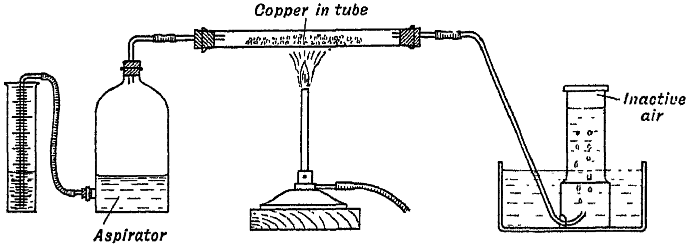


FIG. 203.—When air passes over hot copper, it is deprived of its active part, and the inactive part may be collected.

When copper is heated in air, it gradually blackens and increases in weight. When hot, copper has the power of combining with the active part of the air in just the same way as the iron does gradually when cold, and the black substance formed is copper rust, though it is not generally known by that name. This can be shown by experiment, though not so easily as with iron.

Some copper turnings are placed in a hard glass tube like that shown in Fig. 203, one end of which is connected with an aspirator full of air, and the other by means of a well-fitting cork with a tube which dips under water in a trough. The aspirator is merely a vessel full of air, so arranged that the air in it can be driven out by letting water run into it. Then a cylinder full of water is inverted in the trough of water exactly over the end of the small tube, which dips into it, and is connected with the hard glass tube containing the copper. The copper is heated strongly, and air is forced over it by making water take the place of the air in the aspirator.

As the air passes over the heated copper, the active part joins with the copper to form the black copper rust, and the inactive part passes on into the inverted jar in the trough. That the inactive part collects in the jar is indicated, though not proved, by the fact that it puts out the flame of a taper. If this gas is, in the same way, passed over some more heated copper, it has no effect on it; the copper does not blacken. Moreover, if the amount of air which has come out of the aspirator is measured, and also the amount collected in the jar, it is found that in passing over the copper the air loses *one fifth* of its volume.

Whatever the substance which burns, or rusts, in air—with or without being heated—it uses up the active part of the air, which is called **oxygen**. In every case the same fraction of the air is taken up by the burning or rusting.

PRACTICAL WORK

1. **Substances that burn.**—Place in a crucible supported on a tripod the following substances, each separately : writing paper, small pieces of wood, charcoal, sulphur. Heat the crucible strongly, and allow the flame to come in contact with the substance. Note in each case (i) whether the substance burns, (ii) the colour of the flame, (iii) whether a residue is left, (iv) any other changes observed.

2. **Heating wood without air.**—Place some wood shavings or sawdust in a crucible and exclude the air by covering with a thick layer of sand. Heat the crucible to redness for several minutes. Now tip out some of the sand and note that burning begins as soon as air comes in contact with the wood. Repeat the experiment but allow the crucible to cool before removing the sand. Note that the wood is charred, but that it has not burned.

3. **Heating wood.**—Instead of heating pieces of wood in a crucible, put them in a hard glass tube to which an india-rubber stopper and delivery tube are attached (Fig. 199). Heat the tube gently at first, and afterwards more strongly. What forms on the side of the tube near the stopper? Apply a light to the end of the delivery tube. Does the smoke burn? What is left in the tube?

4. **The burning of wood.**—Cut a long, thin chip of wood ; hold it in a flame until it burns brightly ; then thrust it into a glass bottle, the bottom of which is covered with lime-water to the depth of about half an inch. When the stick ceases to burn, withdraw it and shake the lime-water, which turns milky. A gas which turns lime-water milky is always formed when substances containing carbon burn in plenty of air.

Repeat the experiment with a taper.

5. **A burning candle.**—(*a*) Over a burning candle hold a cold tumbler which has been dried carefully. Notice that the inside of the tumbler becomes covered with mist, and, after a short time, drops of water are formed, which run down the sides of the tumbler (Fig. 200).

(*b*) Wind a piece of copper wire round a small candle and light the candle. Push the top of the wire through a small hole in a disc of cardboard, and then lower the candle into a dry glass jar in such a manner that the top of the jar is covered by the cardboard disc. Observe that the flame of the candle becomes dimmer, and soon goes

out. Water collects on the inside of the jar. Take out the candle, and cover the jar with a greased glass plate. Quickly insert a burning taper, or the relighted candle; the flame is at once put out. Pour in a little clear lime-water and shake it up in the jar; notice that it is turned milky.

Caution.—*In experiments with phosphorus, it is advisable where possible to use the red variety instead of yellow. If yellow phosphorus is used, as it must be for the experiment described in* § 6, *the greatest care should be exercised. It should never be touched by the hands, and should be cut under water. It is liable to catch fire even if left on the bench for a few minutes without water, with which it must be kept well covered.*

6. **The burning of phosphorus.**—Place a tiny piece of phosphorus upon a slate, tile, or an old saucer. Apply a light to it. It catches fire and burns brightly. As it burns, dense white clouds are formed.

7. **Volume of air used.**—Float a flat cork in a large bowl of water. Place a small piece of phosphorus on the cork and light the phosphorus by means of a heated glass rod. Place a large gas-jar over the burning phosphorus and hold it with the mouth below the water until the burning stops. Raise the jar nearly to the surface of the water and notice that the water has risen inside it. Measure the height of the jar and also the height of the water inside it. Hence find roughly what fraction of the air has been used up. When the white fumes have settled down and a clear gas is left, place a glass disc on the mouth of the jar and remove it from the water. Insert a lighted taper. Does it burn or not?

8. **Heating metals in air.**—(*a*) Heat a knitting needle and allow it to cool. Has it undergone any permanent change?

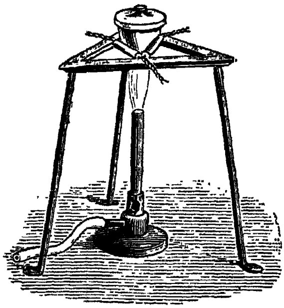


FIG. 204.—Heating magnesium.

(*b*) Heat strongly in a crucible some fragments of copper, tin, zinc and magnesium. Observe all changes that take place. Notice particularly whether the metals melt and what kind of substance is left after strong heating.

9. **Heating of magnesium.**—Weigh a crucible and its lid. Measure 20 cm. of magnesium ribbon, break it into small pieces and weigh it in the crucible. Heat the crucible and contents strongly, taking care to let no fumes escape by keeping on the lid, and only raising it a little when the flame is removed. The magnesium burns brightly in places, but if care is taken, no fumes are lost. When the experiment is finished, a greyish-white powder should be left. Allow it to cool, and weigh the crucible with the lid and powder. Subtract the weight of the crucible, lid, and the piece of magnesium, to

find the weight of the powder. Compare the weight of the powder with the weight of magnesium ribbon.

10. **Rusting of iron.**—Weigh a watch glass with some iron filings, or tacks, in it. Because iron rusts best when damp, add a few drops of water to the iron in the watch glass and allow it to stand for a day or two. At the end of this time warm the watch glass gently, so as to evaporate any water left. When the rusty iron is *dry*, weigh the watch glass and its contents. Its weight will be found to be more after the rusting has taken place.

CHAPTER XXIII

OXYGEN. COMPOSITION OF AIR

Obtaining oxygen from air.—Experiments have been described, in the last chapter, in which the active gas in air, known as oxygen, can be removed. We have now to consider methods of obtaining this gas in order to examine its properties.

Mercury, when heated to 300° C. in the air, slowly combines with oxygen, and gradually becomes converted into a bright red powder, which is the "rust" of mercury. When some of this rust of mercury is heated in a hard glass tube, it soon changes in colour; and as the heating is continued, a mirror-like deposit is formed round the top, cold part of the tube. When this deposit is rubbed with a piece of stick, it runs together and forms little drops of mercury. Moreover, if a glowing splinter of wood be introduced into the tube, it bursts into flame, showing that the oxygen of the air is being driven out of the red mercury rust.

This change is just the reverse of what takes place when mercury itself is heated. The oxygen of the air, with which hot mercury slowly combines, is driven out of the red mercury rust when that is heated strongly. This method is, however, too costly and inconvenient for the preparation of quantities of oxygen.

Preparation of oxygen from potassium chlorate.—A convenient source of oxygen is the white crystalline powder called potassium chlorate. When this compound is heated, it melts and gives off bubbles of oxygen. By mixing the potassium chlorate with a black compound, manganese dioxide, the oxygen from the chlorate comes off more easily and at a lower temperature. This mixture is often called "oxygen mixture". A convenient form of apparatus is shown in Fig. 205.

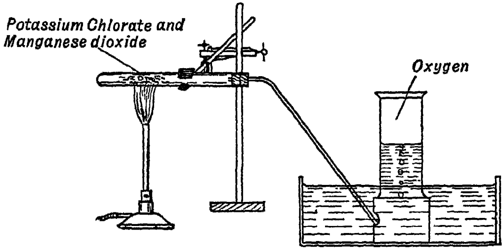


FIG. 205.—Preparation of oxygen by heating a mixture of potassium chlorate and manganese dioxide. The gas is being collected over water.

Properties of oxygen.—Oxygen is a gas which has no colour, no smell, and no taste. It has no action upon litmus paper, and is for this reason said to be **neutral.**

Ordinary combustible substances burn more brightly in oxygen than in the air.

Oxygen has no effect on substances like sulphur and carbon when they are at the same temperature as the room, but if these substances are heated to the point of ignition the oxygen *combines* with them readily, causing them to burn vigorously.

Oxygen is not very soluble in water—one hundred parts by volume of water dissolve three parts by volume of this gas. That the amount of oxygen dissolved by water is small is seen by the fact that oxygen prepared for experiment is collected usually over water. But though the amount is small, it is of great importance, for it is this dissolved oxygen that is used by water animals and plants for respiration.

Oxygen is the part of the atmosphere which is used up in the processes of respiration and also in burning.

Formation of oxides.—Whenever oxygen combines with another element an **oxide** is formed. Indeed, oxygen is so active and powerful that it forms oxides with nearly every simple substance. In all the cases of burning studied, new substances with new properties have been formed; they are therefore chemical compounds, and the experiments afford examples of chemical actions. Thus, when sulphur burns in oxygen, a compound which has a distressing smell

and reddens a moistened blue litmus paper is formed ; it is an oxide called sulphur dioxide.

SULPHUR burning in OXYGEN forms SULPHUR DIOXIDE.

Similarly, carbon burns in oxygen to form a gas which extinguishes a burning taper and turns lime-water milky. This compound is carbon dioxide.

CARBON burning in OXYGEN forms CARBON DIOXIDE.

Again, when phosphorus burns in oxygen, thick white fumes are formed which are the same as those formed by burning phosphorus in air.

PHOSPHORUS burning in OXYGEN forms PHOSPHORUS OXIDE.

An examination of these oxides shows that they are identical with the products formed when the substances burn in air.

Thus, when iron rusts it combines with oxygen to form iron oxide ; zinc, lead and copper when heated unite with the oxygen to form zinc oxide, lead oxide and copper oxide respectively ; and when magnesium, carbon and sulphur burn in air, they form magnesium oxide, carbon oxide and sulphur oxide respectively.

The reaction whereby oxygen combines in this way with a simple substance or even with a complex compound is described as **oxidation**, and the substance is said to have been **oxidised**. The converse process, the removal of oxygen from a body, is known as **reduction**, and the original substance is said to be **reduced**. Thus, mercury is oxidised by heating in air to form mercury oxide ; by further heating, the oxide is reduced, giving the metallic mercury again.

Nitrogen.—The gas left in a bottle of air after iron has rusted in it, or in which phosphorus has burned, will no longer support burning. This gas does not cause damp iron to rust. It is called the inactive part of air. Its chemical name is **nitrogen**.

Properties of nitrogen.—Nitrogen is chemically inactive ; only with difficulty can it be made to combine with any other substance. It does not burn, nor does it *support combustion*. Animals die if put into this gas, because respiration is a form of slow combustion.

Bearing in mind the inactivity of nitrogen, and comparing it ith the very great activity of oxygen, it will be understood that the itrogen in the air dilutes the oxygen, weakens its powers, and ıakes combustion much less intense than it would otherwise be.

If nitrogen obtained from air be heated with either magnesium or thium, both of which can combine with nitrogen, it is found that early 1 per cent. of it remains unabsorbed. This residue is another as present in the atmosphere, and is called argon. **Argon** is also ery inert, more so even than nitrogen. Owing to this, until the ear 1894, its presence in the air was overlooked completely. hortly after its discovery, three other inert gases, **neon, krypton,** nd **xenon,** were found to be present in air in very minute proporons. There are about 12 parts of neon in 1,000,000 parts of air; et the gas is now widely used in illuminated advertising and other gns.

Chemical composition of air.—What may be termed the fundaıental gases in air are, then, oxygen and nitrogen. Carbon dioxide nd water vapour are present practically always; and various other ases, or vapours, frequently occur in small quantities, as impurities. 'he following table shows the percentage compositions of dry air by olume:

Oxygen, a gas which supports combustion	21·00
Nitrogen, an inert gas	78·03
Argon, an inert gas	0·94
Carbon dioxide, a gas which turns lime-water milky	0·03

These proportions are remarkably constant in ordinary air. In he air of mines, however, the oxygen has been found as low as 18·6 er cent., but this represents almost the lowest percentage of oxygen ver obtained from a place where human beings could live. In the ıidst of vegetation, or open ground, especially in the daytime, xygen is present in the proportion of about 21 per cent., because lants under the influence of sunlight release rather more oxygen han they use up in respiration (see p. 260).

The proportion of carbon dioxide rarely exceeds 3 parts in 10,000 ı pure air, and is not often less than 2·7 parts per 10,000. During

the night the proportion is slightly greater than in the day. In th streets of a town the amount of carbon dioxide only exceeds th average amount of the open country by about 1 part in 10,000. I rooms, however, and badly ventilated places, owing to the fact tha human beings use up oxygen and give out carbon dioxide whil breathing, carbon dioxide is often greatly in excess, and oxyge is present in a much smaller proportion than it ought to be Carbon dioxide is not essentially a poisonous gas, but when it occu in excess, the air of which it forms a part is not suitable for huma beings to breathe.

Air always contains a variable proportion of invisible wate vapour, which becomes visible in the form of mist, fog, cloud, rai or dew when the air is cooled. **Ozone** is a peculiar form of ver active oxygen, and is usually present to a very small extent in th air of the open country or over the sea, but not in that of towns.

PRACTICAL WORK

1. **Heating mercury oxide.**—Heat some red oxide of mercury in hard glass test tube, and notice the formation of the silvery, mirro like deposit of mercury around the cold upper part of the tube. Inse a glowing splinter of wood, and watch it rekindle.

2. **Preparation of oxygen.**—(*a*) Powder some crystals of potassiu chlorate, and mix the powder with a little manganese dioxide. Hea some of the mixture in a test tube. Observe, by putting in a glowin splinter, that oxygen is given off.

(*b*) Into a hard glass tube, closed at one end, fit an india-rubbe stopper, with one hole in it, through which a tube, bent as in Fig. 20 is passed. The other end of this tube, called the delivery tube, dip under water in a trough. Mix together some potassium chlorate an manganese dioxide, and place the mixture in the tube. Support th tube and delivery tube as shown in Fig. 205. Fill several gas-jars wit water, and invert them in the trough. Gently warm the tube, an place one of the gas-jars over the end of the delivery tube. As th oxygen is driven off, it displaces the water and gradually fills the ga jar. When the gas-jar is full of oxygen, cover its mouth with a grease glass plate, and lift it out of the trough. In this way fill six jars wit oxygen.

Caution.—*Be careful not to take away the burner from under the har glass tube before removing the delivery tube from the trough.*

3. Properties of oxygen.—(*a*) Take a gas-jar of oxygen (choose one of those collected last). Notice that the gas in the jar has *no colour.*

Remove the plate from the mouth and test its smell and taste; it has *no smell* or *taste.*

Try its effect on moistened litmus papers, blue and red. There should be no effect; oxygen is *neutral.*

(*b*) Into another jar of oxygen thrust a splint of wood red hot at the end. Note the brilliancy of the combustion.

(*c*) Lower a lighted candle into another jar. Note the brightness of the flame.

(*d*) In the next jar hold a piece of red-hot charcoal in a deflagrating spoon. After a time, pour in clear lime-water and note that the remaining gas turns it milky.

(*e*) Make a similar experiment with burning sulphur. Note that a strongly smelling gas is formed, soluble in water and turning blue litmus red.

(*f*) Burn phosphorus in the same way. Note the thick white fumes, which dissolve in water and redden litmus.

CHAPTER XXIV

WATER. HYDROGEN

Heated magnesium or iron takes oxygen out of water.—When iron i left in water, it forms a considerable quantity of iron rust, or iro oxide. But this change from iron to iron oxide may be due to th air dissolved in the water, for if the iron be placed in a tube contair ing water, which has first been well boiled to drive off the air, an the tube is then sealed, the iron does not rust.

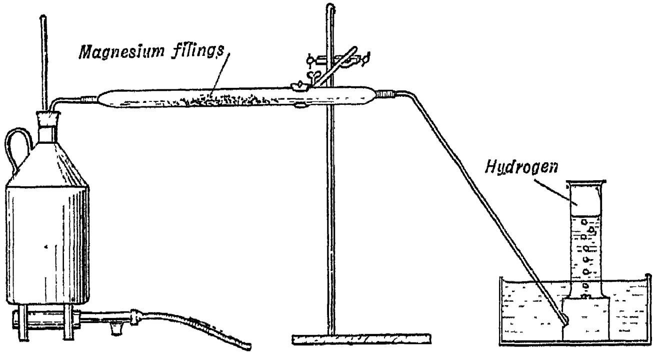


FIG. 206.—The action of steam on heated magnesium.

If, however, magnesium or iron is heated in a hard glass tub (Fig. 206) and water is passed over it in the form of steam, a chemica action begins which teaches several important facts about the com position of water. Not only do the metals become *oxides*, but als a colourless gas, insoluble in water, which can be collected over watei as shown in Fig. 206, is obtained. This gas burns when a lighte taper is brought near it, and the name **hydrogen** has been given to i

In carrying out this experiment, the water in the can should b well boiled, to drive out dissolved air, before connecting up ; afte sufficient gas has been collected, the delivery tube should be take from the trough *before* turning off the gas under the steam can.

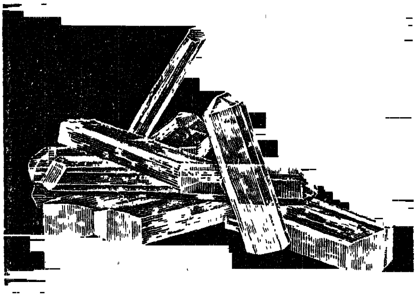


FIG. 207.—Crystals of zinc sulphate.

Composition of water.—Iron in rusting combines with atmospheric oxygen to form iron oxide. Magnesium in burning forms magnesium oxide. When water in the form of steam is passed over the heated metals they become oxides—that is, they combine with oxygen—and hydrogen is also obtained. These experiments show that water contains both hydrogen and oxygen.

Action of zinc on sulphuric acid.—It is now necessary to study the action of metals upon another class of chemical compounds, called acids, which, like the gas formed when sulphur is burnt in oxygen (p. 229), have the power of reddening blue litmus. A typical instance of the action of a metal upon an acid is that of zinc upon sulphuric acid. If pieces of zinc are placed in dilute sulphuric acid they dissolve quickly, and bubbles of hydrogen are given off. If, when the chemical action has stopped completely, the liquid is filtered from the still undissolved zinc, and then partially evaporated in a basin and afterwards allowed to crystallise, clear colourless crystals are formed. This crystalline substance is called zinc sulphate (Fig. 207).

It may therefore be stated that *sulphuric acid and zinc form hydrogen and zinc sulphate.* Or, the same fact may be expressed in another way :

SULPHURIC ACID when acted upon with ZINC gives ZINC SULPHATE and HYDROGEN.

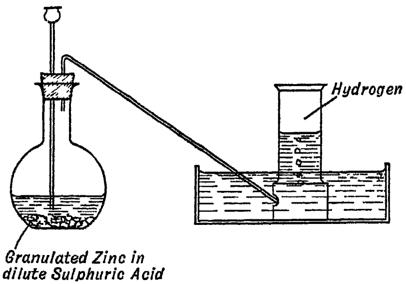


FIG. 208.—Zinc turns hydrogen out of dilute sulphuric acid.

Other metals act in a similar way to zinc.—Zinc is not the only metal which is dissolved by sulphuric acid. The experiment may be repeated using pieces of iron instead of zinc. The iron dissolves in the same manner, and hydrogen is again given off. If the solution obtained is evaporated as before, beautiful green crystals of a sulphate of iron, called green vitriol, will be procured. In the same way, magnesium dissolves, giving hydrogen and white crystals of magnesium sulphate. Many of these substances on heating give off water—known as water of crystallisation—and lose their crystalline shape.

Preparation of hydrogen.—Hydrogen can be obtained both from water and acids by acting upon them under suitable conditions with a metal. The fact that zinc acts upon sulphuric acid, giving off hydrogen, affords a convenient method of preparing hydrogen in fairly large quantities. The apparatus used is shown in Fig. 208. Granulated zinc is placed in the flask, and dilute sulphuric acid poured through the long-stemmed funnel on to it until the open end of the stem is covered. Hydrogen is given off and escapes through the delivery tube, which dips into a bowl of water. It is collected in an inverted gas jar as oxygen was (p. 229).

The apparatus should be air-tight, and before any experiments are done with hydrogen it is essential to be certain that no air is mixed with the gas. A mixture of air and hydrogen explodes when a flame is brought near it ; and unless proper precautions are taken, a serious accident may occur.

Properties of hydrogen.—Hydrogen is a ourless, odourless gas, much lighter than , and consequently can be poured *upwards* m one jar to another (Fig. 209), thus re-rsing the process of pouring water. Hydro-1 burns easily in air. This can be shown fitting an upright delivery tube, the end which is drawn out to a fine jet, to a flask which hydrogen is being generated. Care ıst be taken that all air has been driven t of the flask ; this can be ascertained by ing a test tube with gas by holding it er the delivery tube and removing the st tube, still upside down, to a flame at a distance. When a me burns steadily up the test tube with no explosion, it is safe apply a flame to the delivery tube, when the hydrogen generated ll burn as a steady jet of flame.

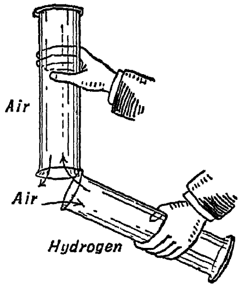


FIG. 209.—Hydrogen is lighter than air and can be poured upwards.

But though hydrogen burns in the air, it will not itself support dinary combustion—that is, hydrogen will not allow ordinary bstances which burn easily in air, such as a candle, to burn in it ig. 210). It can be shown, however, by a suitably arranged experiment that oxygen can be burnt in hydrogen just as hydrogen will burn in air or oxygen.

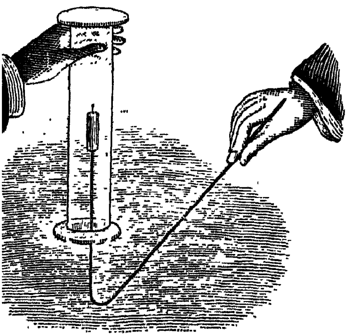


FIG. 210.—The hydrogen burns at e mouth of the jar, but the candle extinguished when inside the jar hydrogen.

When mixed with air or oxygen, hydrogen forms a very explosive mixture ; this is the reason for the care which must be taken in preparing hydrogen gas.

Formation of water by burning hydrogen.—When a jet of burning hydrogen is brought into contact with a cold surface, such as a cold glass, the product of combustion, the oxide of hydrogen, collects as mist, which forms little

drops of colourless liquid. If, after a sufficient quantity of the liquid has been collected, it is examined, it is found

(*a*) to have a density of 1 gram per cubic centimetre ;

(*b*) to freeze at 0° C. ; and

(*c*) to boil at 100° C.

These are the physical characteristics of water and of no other substance, so that this liquid, formed when hydrogen burns, is water.

Previous experiments (p. 235) have shown that water contains hydrogen and oxygen, so that it can now be said that **hydrogen in burning produces water, which is therefore an oxide of hydrogen.**

Hard and soft waters.—Soap lathers easily in some waters and not at all in others. If rain water be used with soap, the lathering takes place with great ease, while the water supplied to houses in some towns gives a lather only with difficulty ; and with sea water there is no lathering at all.

Those waters in which soap lathers easily are said to be **soft.** When this is not the case, the water is spoken of as **hard.** The explanation of the difference is that water dissolves materials out of the rocks below the soil, and these unite with soap, forming a compound of an insoluble kind ; there is no lathering until all the dissolved substances have thus combined with soap, after which the solution and lathering of the soap begins. The soap which combines with the dissolved materials is thus wasted.

Temporary and permanent hardness.—Hard waters differ among themselves. Some can be softened by mere boiling, and when this is the case, the hardness is said to be **temporary.** The presence of carbon dioxide (p. 251) in water gives it the power of dissolving substances which would be otherwise insoluble in it. Chalk, or calcium carbonate, is insoluble in pure water, but in water containing carbon dioxide it dissolves to form a new compound called calcium bicarbonate, which makes the water hard. On boiling the water this compound is decomposed, chalk is again formed and is deposited upon the sides of the vessel, leaving the water soft. The chalk formed in this way is the incrustation commonly known as **fur,**

often found on the insides of kettles and boilers. Magnesium carbonate dissolves in a similar way.

Temporary hardness can also be removed by the addition of lime-water or of washing-soda.

If the hardness is not removed by boiling, and a chemical is required to soften the water, such hardness is said to be **permanent.** Permanent hardness is due to the presence of dissolved sulphates of lime and magnesia. Since these substances are soluble in pure water, mere boiling will not get rid of them. Washing-soda softens such hard water by causing the formation of chalk and insoluble carbonate of magnesia in the place of the dissolved substances.

Sea-water is not usually considered to be a "hard" water, but no lather can be formed with it since ordinary soap is insoluble in water containing a large quantity of common salt.

Pure water can be obtained from water containing either or both soluble and insoluble impurities by means of distillation (see p. 213).

PRACTICAL WORK

1. **Action of a metal on an acid.**—(*a*) Place a few small pieces of zinc in a test tube. Pour a little dilute sulphuric acid upon the zinc and notice if the zinc dissolves. Feel the outside of the tube where the zinc is; what do you notice?

Hold the forefinger of your left hand over the mouth of the tube for a minute, and then, after removing your finger, bring a lighted taper to the tube with your right hand. *Hold the test tube with the open end pointing away from your face.* What do you hear? Does the gas in the tube burn?

(*b*) Place some pieces of zinc in an evaporating dish and add dilute sulphuric acid. Allow the action to go on for some time. Then filter the liquid into another evaporating dish. Evaporate it gently until very little liquid is left. Place the dish on one side to cool. What do you notice after a time? Examine the clear colourless crystals which are formed. Sketch one of the most perfect. Heat a few crystals in a test tube and note that water is given off, and that the crystalline shape is lost.

2. **Preparation of hydrogen.**—Select a flask and fit it up as is shown in Fig. 208. Be careful that both the rubber stopper and the tubes fit closely.

Into the flask put enough granulated zinc to cover the bottom, and add some water. Pour a little sulphuric acid down the thistle funnel, and be sure that the end of the funnel dips beneath the liquid in the flask.

Caution.—*Be careful not to bring a light near the thistle funnel or tube delivering the gas, even when the action in the flask seems to have ceased, or a dangerous explosion may occur.*

Fill a test tube with water and invert it over the end of the delivery tube. When it is full of gas, still holding it upside down, take it to a flame (which should not be near the flask in use); notice that there is a slight explosion. Continue this until the hydrogen burns quietly down the test tube. When this happens fill some gas-jars with the gas, and leave them standing in the trough.

3. Properties of hydrogen.—(*a*) Test one jar of the gas by a lighted candle. Observe that the gas burns at the mouth of the jar and that the candle is extinguished when thrust into the tube; on being taken out, the candle again becomes alight on passing through the flame of the burning hydrogen.

(*b*) Take a full jar of the gas and hold it mouth upwards below a second smaller jar held mouth downwards, as shown in Fig. 209. By testing with a lighted candle, show that the gas leaves the lower jar and fills the upper.

4. Hardness of water.—(*a*) Weigh out about 20 grams of any pure soap. Dissolve it in distilled water by heating. Add water to make a litre of solution. Fill a burette with the soap solution. Place 20 c.c. of distilled water in a stoppered bottle and run the solution into the water a very little at a time, shaking it after each addition. As soon as a lather is formed which does not vanish on standing, note the number of c.c. of soap solution used. Repeat the experiment with (i) 20 c.c. of tap water, (ii) 20 c.c. of tap water which has been boiled and allowed to cool, (iii) 20 c.c. of a solution of magnesium sulphate. By this means compare the amount of hardness in each specimen of water.

(*b*) Pass carbon dioxide (see p. 250) into lime-water until the milkiness first formed disappears. The solution so obtained contains chalk. Boil part of the solution for five minutes. Take (i) 20 c.c. of the unboiled solution, (ii) 20 c.c. of the boiled solution which has been allowed to cool, and (iii) 20 c.c. of the cold solution to which a few drops of lime-water have been added. Compare the hardness of the three specimens as in (*a*), and explain your results.

CHAPTER XXV

MIXTURES AND COMPOUNDS. CHEMICAL FORMULAE

Distinction between mixtures and compounds.—If a mixture of sand and salt, in any proportions, be shaken vigorously with water, the salt dissolves ; the solution will run through a filter, leaving the sand on the paper, and the salt can be recovered by evaporating the filtrate. Iron filings and powdered sulphur, when mixed, can be separated by using a magnet to draw out the particles of iron. Similarly, mixtures of liquids, for example alcohol and water, may be made and again separated by distillation. When two substances, in any proportions, are placed together, so that each component can be distinguished or separated again by some simple process, the substances are said to form a **mixture**.

When magnesium wire is heated in a crucible, it burns with a brilliant flame and leaves a greyish-white residue, totally different from the bright metal. Similarly, phosphorus burns in a jar of air, consuming the oxygen and forming a white powdery phosphorus oxide. Water is produced when hydrogen burns in air. When two substances are mixed and so treated, by heating or otherwise, that they can no longer be distinguished or separated easily, and the new substance has properties unlike those of either, a **compound** is formed, and the substances are said to have **combined**. A *chemical* change or **chemical action** is said to have taken place.

Many experiments have shown that compounds are formed from fixed proportions of the constituents only. One substance will combine with another always in the same proportion, no matter how much of either is used in the experiment.

In a *mixture* the components exist side by side and can be separated by simple mechanical methods. The constituents may be

present in any proportions, and the properties of the mixture are intermediate between those of the constituents.

In a *compound* the components cannot be separated by the simple means suitable in the case of mixtures. The properties of the compound may be quite different from those of the constituents, and these constituents are always present in certain definite proportions, which for each compound are invariable.

In spite of the marked changes which occur in chemical reactions, it has been shown by the most accurate weighing that the total weight remains absolutely unchanged—that is, the total weight of all the products is exactly equal to the total weight of all the components forming these products. This is known as the **Law of the Indestructibility of Matter.**

Air a mixture.—It has been shown that air is made up chiefly of nitrogen and oxygen, in the proportion of four parts by volume of the former to one of the latter. The proportions, however, vary slightly in different places ; for example, inside a closed inhabited room and outside in a field.

Further, whenever a chemical compound is formed, a certain amount of heat is given out or absorbed and there is generally a change of volume. When, however, oxygen and nitrogen are mixed in the proportion in which they occur in the air, there is no evolution or absorption of heat, and no change of bulk, though the mixture cannot be distinguished from air.

Air is, like both oxygen and nitrogen, gaseous and colourless ; like oxygen it supports burning, but the nitrogen reduces the violence of combustion.

When air is shaken up with water, some of it is dissolved. If air were a chemical compound it would be dissolved *as a whole*, and therefore the dissolved part would have the same composition as the undissolved part. But the air which is dissolved in water and can be expelled by heat, contains a greater proportion of oxygen than ordinary air, thus showing that water dissolves more oxygen than nitrogen. When air is liquefied by intense cold and great pressure, and the liquid air is then permitted to evaporate, nitrogen is first given off, so that the liquid becomes richer and richer in oxygen.

If the air were a compound, no one part of it would be more volatile than the other.

We are therefore justified in stating that air is a mixture.

Elements and compounds.—Air is a *mixture* of two distinct gases, oxygen and nitrogen. Water is a *compound* of oxygen and hydrogen, and can be broken up into these gases. By no chemical process can oxygen, nitrogen and hydrogen be split up into simpler substances of different properties. A substance of this kind, which has not yet been split up into simpler substances, is called an **element**. Other elements which have already been mentioned are sulphur, phosphorus, carbon, iron, mercury, lead and magnesium. Some simple compounds which have been studied are the oxides, which are compounds of elements with oxygen, for example, iron oxide and mercury oxide. Other compounds are potassium chlorate, sulphuric acid, salt and sand.

Atoms and molecules.—**John Dalton** of Manchester, in the early part of the last century, revived an old notion of the early Greek philosophers, according to which matter cannot be divided and subdivided indefinitely. A point would be reached when a further subdivision would be accompanied by an alteration of the properties of the substance, due to its decomposition into the elements of which it is composed. For example, given a quantity of the red oxide of mercury, if it were divided into two portions and again and again into two, by and by a further subdivision would mean resolving the red oxide of mercury into the elements oxygen and mercury.

The smallest particle of a substance which can have a separate existence is called a **molecule**. Thus we can speak of a molecule of an *element* like oxygen or iron, and by it we mean the smallest particle which has the properties we associate with oxygen or iron. Similarly, a molecule of a *compound* such as salt or water is the smallest particle which has the same properties as a mass of salt or water.

A molecule can generally be subdivided into smaller parts called **atoms**. An atom is the smallest part of an element that is found to take part in chemical reactions or to occur in chemical compounds. Atoms are thus regarded as chemical units, although an atom itself

is now known to consist of a positively charged nucleus, around which a number of electrons, or negative particles, are in rapid motion. Solid elements, such as iron, zinc and other pure metals, also the liquid metal mercury, are regarded as existing as free atoms. Gaseous elements, such as oxygen, hydrogen and nitrogen, are believed to exist naturally solely as *molecules* consisting each of two atoms firmly linked together, the bonds being broken only by chemical reaction.

Chemical symbols.—For the purpose of expressing chemical changes briefly, chemists have adopted a system of representing elements by letters called **symbols**. These symbols are used to build up **chemical formulae**, each formula consisting of certain symbols representing the amount and kind of the elements present in a compound.

The symbols adopted are usually the first letters of the names of the elements; sometimes the first letters of the Latin names of the elements; and often the characteristic letters of the English or Latin name.

Argon (A), Carbon (C), Hydrogen (H), Nitrogen (N), Oxygen (O), Sulphur (S) are elements represented by the first letter of the English name. Potassium (K) is an example of an element represented by the first letter of its Latin name (kalium).

Aluminium (Al), Barium (Ba), Calcium (Ca), Chlorine (Cl), Magnesium (Mg), Platinum (Pt), Zinc (Zn) are examples of elements represented by the characteristic letters of their English names; while Antimony (Stibium) Sb, Gold (Aurum) Au, Iron (Ferrum) Fe, Lead (Plumbum) Pb, Mercury (Hydrargyrum) Hg are examples of elements the symbols for which are the characteristic letters of their Latin names.

The symbol of an element is used to denote *one* atom of that element; thus O represents one atom of oxygen. A molecule of oxygen, consisting of two atoms, is written O_2, the small numeral following the symbol indicating the number of atoms present. The molecule of water is written H_2O, because the results of analysis show that it consists of two atoms of hydrogen combined with one atom of oxygen. A more complex compound is zinc sulphate;

every molecule of this substance is believed to consist of one atom of zinc, one atom of sulphur, and four atoms of oxygen, and it is written as $ZnSO_4$. Air and other mixtures have no fixed composition, and therefore cannot be represented by formulae.

Formulæ and equations.—Formulae are very convenient for summarising a chemical reaction. Thus when zinc reacts with sulphuric acid to form zinc sulphate and release hydrogen, the reaction may be written :

$$\underset{\text{Sulphuric acid}}{H_2SO_4} + \underset{\text{Zinc}}{Zn} = \underset{\text{Zinc sulphate}}{ZnSO_4} + \underset{\text{Hydrogen}}{H_2}$$

The burning of magnesium in oxygen is represented thus :

$$\underset{\text{Magnesium}}{2Mg} + \underset{\text{Oxygen}}{O_2} = \underset{\text{Magnesium oxide}}{2MgO}$$

In this reaction, two *atoms* of magnesium are represented as combining with one *molecule* of oxygen to produce two *molecules* of magnesium oxide ; the *number of molecules* of a substance taking part in a reaction is indicated by the large numeral coming in front of the formula. It should be noted that the magnesium is represented as two atoms, and not as a molecule ; metallic elements exist as free atoms and do not necessarily form molecules as do gases (see p. 244).

Although the atom of an element is much too small to be weighed on a chemical balance, the relative masses of the different atoms known can be determined. It has been found convenient to make oxygen the standard by which to state these relative masses ; then if one atom of oxygen is given the mass 16, hydrogen is found to be approximately 1, while sulphur is 32, zinc is 65, and magnesium is 24. It will be noticed that no units of measurement are mentioned; these are not necessary because we are dealing solely with the *relative* mass—that is, the *ratio* of the mass of an atom to the mass of that chosen as standard. These relative weights are termed the **atomic weights** of the elements. A list of common elements with their atomic weights is given in the table on the next page.

APPROXIMATE ATOMIC WEIGHTS

	Symbol	*Atomic weight*
Aluminium	Al	27
Barium	Ba	137
Calcium	Ca	40
Carbon	C	12
Chlorine	Cl	35·5
Copper	Cu	63·5
Hydrogen	H	1
Iron	Fe	56
Lead	Pb	207
Magnesium	Mg	24
Manganese	Mn	55
Mercury	Hg	201
Nitrogen	N	14
Oxygen	O	16
Phosphorus	P	31
Potassium	K	39
Silicon	Si	28
Silver	Ag	108
Sodium	Na	23
Sulphur	S	32
Tin	Sn	119
Zinc	Zn	65

These masses can be substituted in the formulae used in describ ing the reactions above, thus :

$$\underset{\substack{(2\times 1)+32+\\(4\times 16)=98}}{H_2SO_4} + \underset{65}{Zn} = \underset{\substack{65+32+\\(4\times 16)=161}}{ZnSO_4} + \underset{2\times 1}{H_2}$$

$$\underset{2\times 24}{2Mg} + \underset{2\times 16}{O_2} = \underset{2(24+16)}{2MgO}$$

It is then readily seen that the total relative mass of the product is equal to that of the reacting substance. This is another way o expressing the law of indestructibility of matter in chemical reaction (see p. 242). It also provides another meaning for the symbc " = " which has been inserted between the reactants and th products, showing that, as in algebra, it means "equal to" a regards relative mass. Hence the statement of a chemical reactio by means of formulae is known as an equation, and, like the equatio used in algebra, the two sides must balance. Thus in writin chemical equations, it is necessary to see that every atom repre sented on one side also appears on the other.

PRACTICAL WORK

1. **A mixture of sand and salt.**—Make a mixture of sand and salt by grinding up the two substances in a mortar. Place the mixture in a gas-jar, add water and shake the mixture vigorously. Filter it and run a little hot water through the filter paper. Sand remains on the filter, and the salt can be recovered by evaporation of the filtrate.

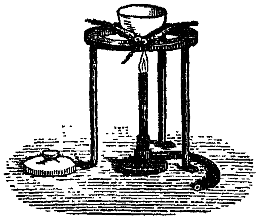


FIG. 211.—Heating together a mixture of iron filings and sulphur.

2. **A compound.**—(*a*) Mix together small heaps of iron filings and powdered sulphur intimately to form one heap. What is the colour of the mixture? Bring one end of a bar magnet to the mixture. Try to obtain the separate heaps of iron and sulphur with which you started.

(*b*) Put some of the mixture of iron and sulphur in a crucible, and support it in a pipeclay triangle on the tripod stand (Fig. 211). Heat the crucible. Observe that the sulphur melts and some burns away. Add more sulphur, and continue to heat the mixture until no more sulphur burns away. Examine the product so obtained.

When the crucible and its contents are cold, loosen the contents and bring one end of a bar magnet to them. Are they attracted? Do they look like either iron filings or sulphur?

(*c*) Into a test tube put a little iron filings; into a second put some powdered sulphur; and into a third a little of the product obtained by heating iron filings and sulphur together.

To each test tube add a few drops of dilute sulphuric acid. Notice what happens in each case. In which tubes are bubbles of gas formed? Smell the gas. Soak a strip of blotting paper in a solution of lead acetate and hold it in the mouth of the test tube.

CHAPTER XXVI

CARBON AND CARBON DIOXIDE

Kinds of carbon.—Carbon is a substance which is widely distributed in nature, substances containing it being present in all living matter, whether animal or vegetable; carbon occurs also in most products formed by animals and plants during their lives. Carbon compounds of this kind, whether formed in plant or animal tissues or prepared artificially, are called **organic** compounds. All other chemical compounds, whether containing carbon or not, are **inorganic.**

Carbon occurs, combined with other substances, in many rocks, being a constituent of all the minerals known as **carbonates.**

Combined with oxygen as carbon dioxide, carbon is found in the atmosphere and dissolved in spring waters.

Of the various forms of carbon found in nature the purest and the most valuable is the **diamond**, which is crystalline and very hard,

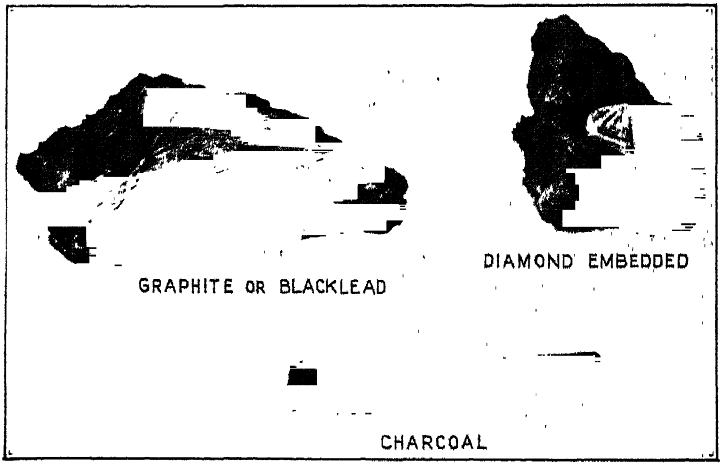


FIG. 212.—Forms of carbon.

being capable of scratching all other materials. It is the most brilliant of gems. Diamond is proved to consist of carbon by burning it in air or oxygen, when the same oxide of carbon, **carbon dioxide**, is formed as when charcoal or other kinds of carbon are burnt with plenty of air or oxygen.

Diamonds are found in South Africa, Brazil and Australia, but many famous diamonds have been found in India, the mines at Golconda in Hyderabad being specially noted.

Blacklead or **graphite** is another form of almost pure carbon, with properties totally different from those of the diamond. It is opaque and black, and so soft that it will mark paper. It is really a crystalline form of carbon, although good crystals are not common. It occurs naturally and is mined in California, India and Ceylon, and was formerly largely obtained from Cumberland in England. It is now prepared artificially on a large scale at Niagara in North America. Graphite is used in the form of powder as a lubricant—that is, a substance to make the various parts of machines work smoothly ; and as a means of making wax surfaces conduct electricity for the purpose of electrotyping. The " lead " of lead pencil is compressed graphite.

Amorphous varieties of carbon.—Other forms of more or less pure carbon in an **uncrystallised** or **amorphous** state are **coke** and **gas carbon**, which result from the heating of coal * ; **lampblack**, which is the carbon deposited by oils, etc., burning in an insufficient supply of oxygen ; and **wood charcoal**, obtained by heating wood in closed retorts, or in stacks under earth. The last method, which is the oldest, is still in use in the Punjab. Billets of wood are stacked round a rough central chimney and the whole is covered with earth or turf (Fig. 213). The stack is set alight and allowed to burn slowly, air being admitted through holes in the bottom. In the more modern retort method, the valuable volatile products, such as acetic acid, are collected, whereas in the old method these are wasted.

* The term " amorphous " is derived from the Greek word αμορφος, or *amorphos*, and means shapeless. It is applied to any substance which has no definite crystalline form.

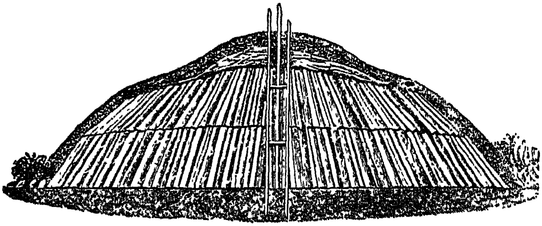


FIG. 213.—An old method of making wood charcoal.

Animal charcoal or bone-black, which is left in the retorts when bones are distilled, has the power of absorbing colouring matter, and on this account it is used for decolorising solutions coloured by organic matter. Animal charcoal is really a misleading term, as the quantity of carbon present is usually only about 10 or 12 per cent., the remainder being chiefly bone ash. **Gas carbon** (p. 254) is a good conductor of electricity, and is used to make the carbons of arc lamps and also for the brushes of dynamos and motors.

Both animal and wood charcoal are very porous substances, and they have the power of absorbing gases to a large extent. Both kinds of charcoal are useful in removing harmful vapours. Wood charcoal is used considerably in Europe for heating purposes. Whenever any of the kinds of carbon burn freely in a good supply of air or oxygen, carbon dioxide is formed, thus affording evidence that the three varieties of carbon are chemically identical in character.

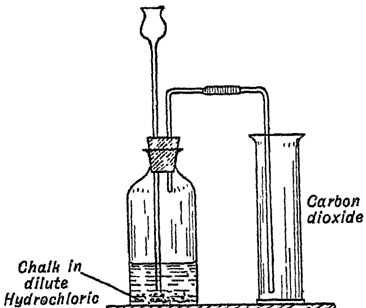


FIG. 214.—Apparatus for preparation and collection of carbon dioxide.

Preparation of quantities of carbon dioxide.—Carbon dioxide is produced by burning carbon in air or oxygen (p. 230), but there are more convenient ways of obtaining the gas. When an acid is added to marble or chalk, a gas is given off which puts out flames, turns clear lime-water milky, and is, in fact, carbon dioxide. Quantities of the gas may be prepared

by placing pieces of marble about the size of peas in a bottle fitted like that in Fig. 214 and pouring dilute hydrochloric acid down the thistle funnel. When the acid comes into contact with the marble, the gas is given off:

$CaCO_3$	+	$2HCl$	=	CO_2	+	$CaCl_2$	+	H_2O
Chalk		Hydrochloric acid (2 molecules)		Carbon dioxide		Calcium chloride		Water

Enough acid is poured in to cover the lower end of the funnel, so that the gas cannot escape up the funnel. The gas given off is heavier than air, and can therefore be collected as shown in Fig. 214; as the gas accumulates in the jar, the air is pushed out at the top. Several jars can be filled in this way.

Properties of carbon dioxide.—The gas is colourless and has no smell. As it is heavier than air, it can be poured downwards like a liquid (Fig. 215). Carbon dioxide is slightly soluble in water, and the solution which is formed turns blue litmus paper red. Many acids will do this, and also redden a solution of litmus; for this reason the solution of carbon dioxide in water is often called **carbonic acid**, and the carbon dioxide itself is sometimes spoken of as **carbonic acid gas**. Carbon dioxide has the property of extinguishing the flame of a taper or match, and is consequently a non-supporter of combustion.

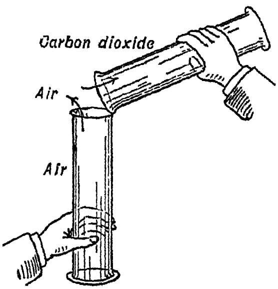


FIG. 215.—Carbon dioxi[de] gas is heavier than air a[nd] can therefore be poured fro[m] one vessel into another, li[ke] a liquid.

Action of carbon dioxide on lime-water.—When carbon dioxide is passed into lime-water a milkiness is seen; but if the passage of the gas be continued, the milkiness by and by disappears. If the clear solution whi[ch] results after the disappearance of the white precipitate be boiled, t[he] milkiness again appears. The reason for this is that the wh[ite] precipitate, which is **chalk**, dissolves in water which has beco[me] saturated with carbon dioxide—that is, in carbonic acid. W

the clear solution, which appears after solution of the powder, · boiled, the carbon dioxide is driven out of it, and the liqui again becomes pure water. The precipitate reappears becaus it will not dissolve in pure water. The clear solution produced b passing carbon dioxide into the milky liquid is thus similar to wat with temporary hardness (p. 238), although generally a natural wat will not contain so much chalk.

Carbon monoxide.—When a coal or coke fire is red hot and glow ing, a pale blue flame may often be noticed burning at the bac of the fire. This is the flame of carbon monoxide, an oxide c carbon containing less oxygen than carbon dioxide. This com pound is also formed when steam is passed over white-hot coke, an hydrogen is produced at the same time. The mixture of these tw gases, carbon monoxide and hydrogen, is known as **water gas**, an is mixed with ordinary coal gas for heating and lighting purposes it is also generated in special plants to drive certain types of ga engine.

$$\underset{\substack{\text{Water}\\\text{as steam}}}{H_2O} + \underset{\text{Carbon}}{C} = \underset{\substack{\text{Carbon}\\\text{monoxide}}}{CO} + \underset{\text{Hydrogen}}{H_2}$$

Carbon monoxide is extremely poisonous.

Distillation of coal.—Coal is an impure form of carbon, containin as impurities hydrogen, sulphur, oxygen and nitrogen in variou compounds. In the manufacture of **coal gas** it undergoes **destructiv distillation**. Coal is heated to a red heat in retorts for about four hour (Fig. 216). At the end of this time all the volatile matter has bee driven off and coke is left in the retorts. The gaseous products firs pass into the **hydraulic main**, which is a trap to prevent the return c the gases to the retorts. Here some coal tar and a gas called am monia, which is a compound of nitrogen and hydrogen having pungent smell, condense, but most of the tarry matter, as well a liquor containing ammonia compounds, remains in the **condensers** The remainder of the ammonia is absorbed by a stream of wate which is continually flowing down the **scrubbers**. The gas nex passes into the **purifiers**, which contain iron oxide, to remove othe gases such as hydrogen sulphide and carbon dioxide, which woul

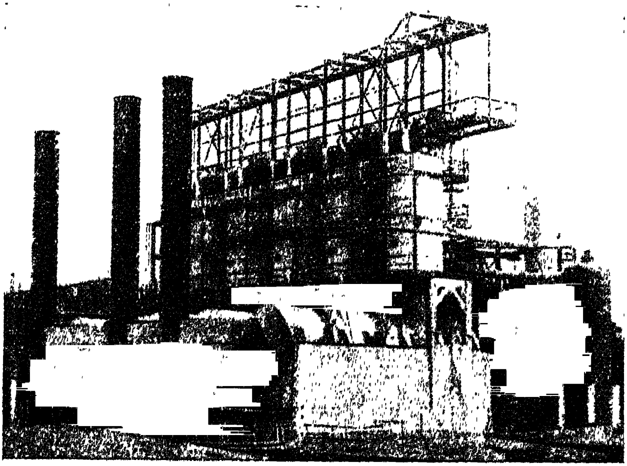


FIG. 217.—Distilling plant at a petroleum refinery.

or **petrol**; that which is condensed at 150°-250° C. is **kerosene**, used for burning in oil lamps; while that which is condensed at 250°-350° C. is used as **fuel oil**. The residue in the boilers is treated with superheated steam and yields lubricating oils of various grades, vaseline and paraffin wax. The final residue is **bitumen** or **asphalt**, which are black solids used in making waterproof roads, for making walls watertight, lining brick tanks, etc.

PRACTICAL WORK

1. Occurrence of carbon.—Heat separately a number of animal and vegetable substances, such as meat, wood, rice, egg, etc., in a crucible, and notice in each case the production of a black residue, consisting largely of carbon. Heat the crucible more strongly, and observe that the black residue burns away, leaving an almost colourless ash.

2. Properties of carbon.—(*a*) Examine and write down the properties of as many of the following forms of carbon as you can obtain: black-lead, wood-charcoal, bone-black, and soot.

(*b*) Show that charcoal floats in cold water. In boiling water charcoal sinks after a time, and then will not float again unless thoroughly dried. This is because air is driven out of the charcoal by the warmth of the water, and the charcoal becomes *waterlogged.*

3. Preparation of carbon dioxide.—Fit a bottle with a cork in which two holes are bored. Pass a long-stemmed thistle funnel through one hole and a right-angled piece of tubing through the other. To the latter connect a delivery tube as in Fig. 214.

Place small pieces of marble or lumps of chalk * in the bottle. Pass the delivery tube through a disc of cardboard resting on the top of a gas-jar. Pour dilute hydrochloric acid down the funnel. During the effervescence a gas is given off and collects in the jar. When a burning taper is extinguished immediately it enters the jar, take out the delivery tube and put it into a second jar. Cover the first jar of gas with a disc of card. In the same way collect several jars of the gas.

4. Properties of carbon dioxide.—(*a*) Examine in succession the jars of carbon dioxide now prepared. Notice that the gas is invisible and without taste or smell; extinguishes a lighted taper; must be heavier than air or it could not be collected in the way described.

(*b*) Pour the gas downwards from one jar into another, as shown in the diagram (Fig. 215), and test both jars by a lighted taper. It will be seen that the lower jar contains the carbon dioxide.

(*c*) Pour a little water made blue with litmus into a jar of the gas and shake it up. A little of the gas dissolves, and the colour of the solution turns red. Boil the solution; the carbon dioxide is driven off, and the blue colour of the litmus is regained.

(*d*) Pass the gas from the delivery tube through some lime-water. Observe that a milkiness is produced, owing to the production of a white powder, which disappears after a short time. Boil the solution thus obtained, and notice that the milkiness again appears. Filter the milky solution, and so obtain the white powder on a filter paper. Put the filter paper with the precipitate into a test tube and add a few drops of dilute hydrochloric acid. Notice the effervescence. Test the gas which is given off; it puts out a flame.

5. Coal products.—Heat some coal dust in a hard glass test tube. Bring a lighted taper to the mouth of the test tube, and notice that a gas which burns readily is being given off. Drops of a tarry liquid may be condensed on the sides of the test tube.

* Not "blackboard chalk", which is made of calcium sulphate, or gypsum, whereas chalk and marble are calcium carbonate.

CHAPTER XXVII

COMBUSTION AND RESPIRATION

Flame.—The term combustion has been used to describe the burning of substances in air or oxygen. It is also used to describe any chemical reaction producing heat and light. Combinations between gases, or involving substances which give off inflammable vapours on heating, such as wood or coal, are always accompanied by flame.

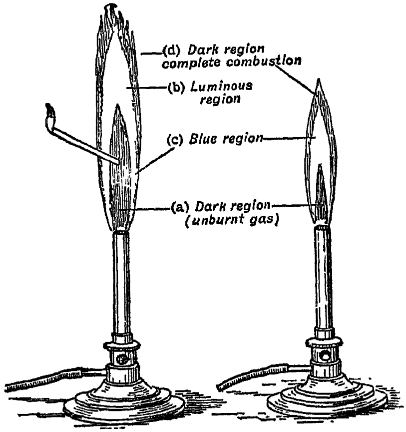
Three distinct parts or zones may be seen in an ordinary gas flame (Fig. 218, left).

(i) A dark inner zone (a) consists of unburnt gas: the nature of this gas may be examined by holding one end of a narrow glass tube in the flame at this place and applying a light to the other end. This zone contains *unburnt gas.*

(ii) Outside the dark inner zone is found the brightest part of the flame (b): this makes up the largest part of the flame, and is the zone from which *soot* is deposited on a cold object. In this zone the gases are partly burnt.

(iii) Outside the bright zone is an almost colourless envelope (d): in this zone burning is completed. This shows a small bright blue region at the base of the flame (c).

The flame of a candle or of an oil-lamp, if examined, is found to consist of the same parts as a gas flame although the shape may be different. The substances which give rise to the flames of a candle and of an oil-lamp are respectively solid and liquid; they are raised to the temperature of ignition by a burning match, so that a certain amount is vaporised and a flame is produced. As this material is used up, more liquid, formed by melting of the wax in the case of the candle, is drawn up the wick by capillary attraction.



Air-holes shut. Air-holes open.

FIG. 218.—Structure of luminous and non-luminous flames.

The Bunsen flame.—This flame, when the air-holes of the burn are open (Fig. 218, right), consists of (i) a zone of unburnt gas at tl base as before—in this case bluish with a brighter edging—and (ii) faint blue cone surrounded by an almost invisible region of complet combustion. The air admitted at the base of the Bunsen burn causes combustion to go on inside the flame as well as outside. Th causes the carbon which would otherwise be deposited as so to be burnt away to carbon dioxide. It will also be notice that the zone of unburnt glass is smaller than it is when tl air-holes are shut. The flame of the Bunsen burner with tl air-holes open is hotter, particularly in the blue region, than tl luminous flame.

Luminosity.—The fact that the ordinary gas flame deposits so and is luminous, and that the Bunsen flame deposits no soot and not luminous, is good evidence that the luminosity of the ordinar flame is due to the presence of minute particles of soot—that is, carbon. This is, in fact, the case, as may be proved by holding piece of smouldering brown paper near the air-holes, when the so

carried up by the draught causes the flame again to become luminous. At the high temperature of the flame, these carbon particles become white hot or **incandescent.**

This principle, that solid substances placed in a non-luminous flame cause it to give out light, is applied in the ordinary **incandescent burner.** Oxides of certain rare metals are found to be especially effective in this respect, and the incandescent mantle contains a mixture of the oxides of two metals, cerium and thorium.

Products of burning.—When a candle burns, carbon dioxide and water vapour are given off (see p. 219). If the tests by which these results were obtained are repeated either with a gas flame or with the flame from an oil-lamp, they give exactly the same results. The gas, the candle and the oil consist chiefly of hydrogen and compounds of hydrogen and carbon, and these simply undergo combustion.

Carbon dioxide is given off in respiration.—When a person blows with the mouth into clear lime-water it is quickly turned milky. From this important fact it appears that carbon dioxide escapes from the mouth in breathing; and it does so from every living animal as a result of respiration. It does not matter how small an animal or plant is, all the time it is alive it is continually adding to the atmosphere a certain amount of carbon dioxide.

It has been seen that carbon dioxide is formed by the burning of carbon, or of a substance such as wood, which contains carbon. It is formed by the combination of carbon with oxygen. Animal and plant tissues consist largely of compounds of carbon, and portions of these are being continually used up to provide energy for the activities of life. They are used up by a process of slow combustion, without, of course, any actual burning. The oxygen necessary for this is brought to animal tissues by the blood, and the carbon dioxide formed is taken away by the blood. Impure blood containing carbon dioxide passes into the lungs, where it gives up its carbon dioxide to the air and acquires a fresh supply of oxygen, which it carries away to the tissues of the body. This process is known as **respiration.**

That there is always a certain amount of carbon dioxide in the air

can be proved by exposing fresh lime-water in a shallow vessel Soon the lime-water becomes covered with a thin white layer c chalk, which is formed by the combination of the carbon dioxide i the air with the lime in the lime-water. One reason why there i never much carbon dioxide in the air out of doors is because ther is an agency continuously at work getting rid of this gas. Thi agency is the green parts of trees and other plants.

The green part of a plant, when exposed to light, uses up carbo dioxide and releases oxygen, a process called **photosynthesis.** I this way, although plants are continually producing carbon dioxid by respiration, by photosynthesis they keep the proportion of carbo dioxide, formed by them and by animals, in the atmosphere at nearly constant proportion.

PRACTICAL WORK

1. **Flame of Bunsen burner.**—(*a*) Examine the flame of a Bunse burner (i) with the air-holes closed, and (ii) with the air-holes open Draw each flame and describe the different parts. Compare (i) witl the flame of a candle and of an oil-lamp.

(*b*) Place a narrow glass tube in the inner dark part of each flame an put a light to the other end of the tube. What do you notice?

(*c*) Close the air-holes of a Bunsen burner, then very gradually ope them. Note that the middle bright part of the flame becomes smalle and smaller and finally vanishes.

2. **Animals breathe out carbon dioxide.**—(*a*) Blow through a piece o glass tube into some clear, freshly-made lime-water in a tumble Milkiness is at first produced, but if the blowing be continued lon enough the milkiness disappears.

(*b*) Fill a jar with water and invert it in a basin of water. Blow ai from your lungs into the jar by means of a tube. When the jar is ful of air, place a glass plate under it and lift it out of the water. Shov that the air will extinguish a lighted taper.

(*c*) Repeat the two preceding experiments by blowing air from bellows instead of from the lungs. Notice that this unbreathed air ha not the same effects upon a lighted taper or lime-water as breathe air.

3. Carbon dioxide in the air.—Pour some clear lime-water into a blue bowl, or some other shallow vessel of a dark colour. Leave it exposed to the atmosphere for a little while. Notice the thin white scum formed on the top. The carbon dioxide in the air has turned the top layer of liquid milky.

CHAPTER XXVIII

ACIDS, BASES AND SALTS

Acids.—When sulphur is burnt in air or oxygen, the gas produce dissolves in water to form a liquid which reddens blue litmu Similar results are obtained if phosphorus or carbon be substitute for the sulphur. The liquids thus formed, which have the power (reddening blue litmus, have been called **acids.** Hydrochloric, su phuric and nitric acids are among the commonest acids. These thr compounds all have a sour taste, and all turn a blue litmus pap red. Almost all acids have these two properties. In addition, **acids contain hydrogen,** which can, in suitable circumstances, be r placed by a metal. The metal may itself turn out the hydrogen l acting on the acid directly. An example of this is afforded by t preparation of hydrogen by acting on sulphuric acid with zinc. C the hydrogen of the acid may be replaced by the metal in a co pound like caustic soda (sodium hydroxide), or lime (calcium oxid Thus the general properties by which an acid may be recognised a its **sour taste and its power of turning blue litmus red ; further, it conta hydrogen, which can be replaced by a metal.**

Bases and salts.—Substances belonging to another class of co pounds, of which sodium hydroxide and lime-water may be tak as typical examples, all possess properties of an opposite charac to those which distinguish acids. They all have the power of d troying, or **neutralising,** the properties of an acid. These compour are called **bases.** One group of bases, which have been known si ancient times, namely, caustic soda, caustic potash and ammo solution, are often called **alkalis.**

Bases are compounds of a metal with oxygen and hydro known as **hydroxides.** When added to an acid, the metal of the b replaces the hydrogen of the acid forming a compound known

a salt. This is a fact of great importance. It may be written thus :

A BASE $\begin{matrix}\text{when} \\ \text{acted} \\ \text{upon} \\ \text{by}\end{matrix}$ an ACID gives a SALT and WATER.

This statement provides a definition of a base. It may be said that :

A base is usually a hydroxide of a metal and is capable of neutralising an acid.

Among the bases mentioned already are lime, magnesium oxide, caustic soda and caustic potash.

The statement that when a base is acted upon by an acid, a salt and water are formed, also furnishes a convenient definition of a salt, which may be expressed thus :

A salt is a chemical compound formed by acting upon an acid with a base, in this way replacing the hydrogen of the acid with the metal.

An example of neutralisation.—When the soluble base, sodium hydroxide or caustic soda, is dissolved in water, a solution is obtained which feels soapy or slimy to the touch, and has the power of turning a reddened litmus paper blue again. A dilute solution of hydrochloric acid, on the other hand, has a sour taste and will redden a blue litmus paper. If, to a little of the solution of sodium hydroxide contained in an evaporating basin, dilute hydrochloric acid is added drop by drop, a point is soon obtained, which can be discovered by dipping both a red and a blue litmus paper in the liquid, when the solution has no effect on litmus at all. The liquid is said to be **neutral**. It has neither acid properties nor alkaline properties. Moreover, if this neutral solution be evaporated gently to dryness, it is easy to prove by tasting it, and by examining the shape of the tiny crystals of which the residue is made, that the substance obtained is sodium chloride or common salt. Hence,

$$\underset{\substack{\text{Sodium} \\ \text{hydroxide}}}{NaOH} + \underset{\substack{\text{Hydrochloric} \\ \text{acid}}}{HCl} = \underset{\substack{\text{Sodium} \\ \text{chloride}}}{NaCl} + \underset{\text{Water}}{H_2O}$$

If sulphuric acid had been used instead of hydrochloric acid, a similar change would have taken place, sodium sulphate being formed :

$$2NaOH + H_2SO_4 = Na_2SO_4 + 2H_2O.$$

With nitric acid, sodium nitrate is formed :

$$NaOH + HNO_3 = NaNO_3 + H_2O.$$

Sodium chloride, sodium sulphate and sodium nitrate are salts. Among other salts which have been mentioned are: potassium chlorate, zinc sulphate, magnesium sulphate and potassium nitrate.

PRACTICAL WORK

1. **Alkaline substances.**—(*a*) By the help of a pair of crucible tongs, *so as to avoid touching it with the hands*, place a very small piece of sodium in a little water contained in an evaporating basin. When the chemical action has ceased, dip a finger in the solution and rub the liquid between finger and thumb. What do you notice? Afterwards evaporate the liquid to dryness. Examine the solid produced, and compare it with caustic soda. Place a piece of moistened red litmus paper in contact with the solid. It is turned blue.

(*b*) Burn some magnesium and collect the greyish-white solid formed. Observe that it is a powder apparently insoluble in water, and that it glows when strongly heated, but does not undergo any further chemical change. Place a little of the powder on a moistened red litmus paper and observe that the latter is turned blue.

(*c*) Examine a piece of lime. Note its effect on litmus paper, its slight solubility, and the action of heat.

2. **Neutralisation.**—(*a*) Make a solution of sodium hydroxide. To a portion of the solution in an evaporating basin add dilute hydrochloric acid, drop by drop, until the solution has no effect upon either a red or blue litmus paper. The solution is then said to be *neutral*. Gently evaporate the solution on a sand-bath until a dry white residue is left. Then, by tasting a few particles of the solid, satisfy yourself that it is common salt, or sodium chloride.

Redissolve, in very little hot water, the sodium chloride formed in the last experiment, and place the solution on one side to evaporate slowly. Examine, under a magnifying glass, the residue formed. What is the shape of the crystals?

(*b*) Repeat the last experiment, substituting dilute sulphuric acid for hydrochloric acid. In this way sodium sulphate crystals are obtained instead of crystals of common salt.

(*c*) Repeat the experiment, but use dilute nitric acid. Sodium nitrate crystals are obtained.

are gypsum or calcium sulphate ($CaSO_4$), and heavy-spar or barium sulphate ($BaSO_4$). Enormous deposits of gypsum are found amongst the sandhills of Rajputana and in the Punjab. Heavy-spar or barytes occurs in the Kurnool district of Madras.

Sulphur is also a constituent of many organic compounds. It is present in wool and hair, the pungent principles of garlic and onions are sulphur compounds, while the tarnishing of silver by white of egg and by rubber is due to sulphur compounds in these substances.

Varieties of sulphur.—Sulphur exists in several forms. Elements which have more than one form, all of them with the same chemical composition but possessed of different physical properties, such as density, colour, crystalline form, are said to show **allotropy**, and the different varieties of the substances are called **allotropic forms** or **allotropes**. Sulphur, oxygen, carbon and phosphorus all have allotropic forms. Sulphur has several allotropic forms, though it is only necessary to mention two of them. These are **octahedral** and **plastic** sulphur. All the varieties consist entirely of sulphur.

Octahedral sulphur.—Ordinary roll-sulphur, or brimstone, is composed of tiny crystals of this variety of sulphur compactly massed together. This can be seen by breaking a roll of sulphur into two and examining the broken ends, when crystals will be distinctly visible in the centre of the roll. But much larger crystals are obtained by dissolving powdered roll-sulphur in carbon disulphide and allowing the solution to evaporate slowly into the air, when fairly large, octahedral crystals of sulphur will be obtained (Fig. 223). This

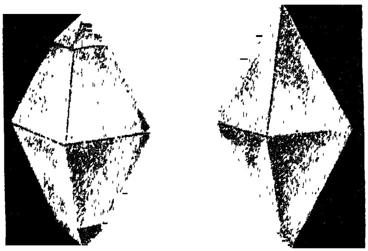


FIG. 223.—Large octahedral crystals of sulphur.

kind of sulphur is the most *stable* form ; the other varieties gradually change into octahedral sulphur if left exposed to the air.

Plastic sulphur.—When boiling sulphur, which may be obtained by heating powdered roll-sulphur in a large test tube, is cooled suddenly by pouring it into cold water, it undergoes a remarkable change. A piece of the sulphur solidified in this manner is very like rubber ; it can be pulled about like rubber, and is as elastic. This springy material is **plastic** sulphur. But if plastic sulphur be left to itself for a day or two, it changes back into octahedral sulphur—another reason for regarding the octahedral as the stable form of the element. In this process of reconversion there is no change of weight.

Effects of heat upon sulphur.—Sulphur undergoes a series of changes as it is heated. To follow the changes satisfactorily, the heating must be gradual. When powdered roll-sulphur is heated in a large test tube it first melts, at about 114° C., into an amber-coloured liquid, which when poured into cold water solidifies into ordinary yellow sulphur. On continuing to heat the melted sulphur above 114° C., however, it gradually gets darker and darker in colour, becoming thicker and thicker in consistency until at about 250° C. it is so viscous or slow-flowing that the tube containing it can be inverted and the liquid will not flow. But if the temperature be still further raised, the thick liquid becomes thin and mobile again, and at 445° C. it boils, changing into a dark orange-red vapour. The vapour, by sudden cooling, is deposited as a yellow powder, known as "flowers of sulphur". When the boiling sulphur is poured into cold water, it is converted into plastic sulphur.

Oxides of sulphur.—Sulphur forms two different compounds with oxygen—one called **sulphur dioxide** (SO_2), the other **sulphur trioxide** (SO_3). The latter compound contains half as much oxygen again as the former.

Sulphur dioxide.—The simpler oxide of sulphur is formed when sulphur burns in air or oxygen :

$$S + O_2 = SO_2.$$

The only difference in these two cases of burning is that when the sulphur combines with the oxygen of the air the combustion is feebler, and the sulphur dioxide formed is mixed with the nitrogen

respects from the ordinary variety; on repeating with red phosphorus the various experiments performed already with the yellow form, it will be found to be insoluble in carbon disulphide, and to ignite only when strongly heated (240° C.). It is not luminous, neither does it oxidise when exposed to moist air. It need not therefore be kept under water. Red phosphorus consists of minute crystals, although it is sometimes wrongly called amorphous phosphorus; it is non-poisonous.

Phosphorus and oxygen.—When phosphorus burns it forms a compound called **phosphorus pentoxide.** This is the product of combustion when either red or yellow phosphorus is used, and this fact may serve to prove that the two varieties are chemically identical. This oxide is readily obtained as dense white fumes when phosphorus is burnt in either air or oxygen:

$$4P + 5O_2 = 2P_2O_5;$$

these fumes settle as a white amorphous powder which dissolves very readily in water with a hissing noise, forming an acid solution.

When exposed to the air, the oxide absorbs moisture, being, in fact, one of the most powerful of drying agents, on account of which it is frequently used as a **dehydrator** or drying agent (*i.e.* for the purpose of removing moisture from gases or liquids). For the same reason it is of service in promoting many chemical reactions of which the essential part is the removal of the elements of water. When it dissolves in water a solution of **phosphoric acid** is formed:

$$P_2O_5 + H_2O = 2HPO_3.$$

How man makes fire.—Every race of mankind, however unenlightened, understands how to make and use fire, and there is no historical record of any nation or tribe which lacked this knowledge. The use of fire was one of man's first and greatest discoveries. The original method of getting it, still in use amongst some primitive peoples, was by rubbing together two pieces of wood. The Tahitian produces fire in a few seconds by rubbing a wooden stick in a groove in another piece of wood. A more usual method, used by the natives of Australia and in some parts of India, is as follows: Two pieces of soft dry wood are chosen, one a stick 8 or 9 inches long,

FIG. 227.—Production of fire by friction of wood.

which is bluntly pointed. The other is flat. Fire is produced twirling the stick rapidly between the two hands and at the sa: time pressing the pointed end on the flat surface.

In the " Iron Age " this method of obtaining fire was replac among the more civilised peoples by the striking together of fl

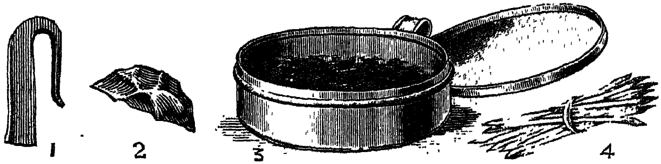


FIG. 228.—Tinder-box.

1. The steel. 2. Th flint. 3. Box with tinder. 4. The sulphur matches

and steel, some inflammable material being present to which a flame could be communicated. Even in the beginning of the nineteenth century this simple plan was almost the only available means of getting fire, although the Greeks and Romans sometimes obtained it by concentrating the sun's rays through convex lenses (burning glasses). The **tinder-box** of the early nineteenth century (Fig. 228) needed, as well as the flint and steel, the inflammable tinder consisting of half-burned linen or some similar substance, and a match tipped with sulphur by means of which a flame could be obtained from the glowing tinder.

Matches.—The first matches, called "dipping matches", consisted of splints of wood tipped with a mixture of sugar, potassium chlorate and gum. These splints were ignited by dipping the heads into concentrated sulphuric acid. Owing to the dangerous nature of the substances employed they never became popular.

The first friction lights or matches were tipped with antimony sulphide and potassium chlorate, and were ignited by rubbing the heads between folds of sandpaper. The heat thus produced causes the sulphur in the sulphide to combine with the oxygen of the potassium chlorate and to ignite.

The modern match industry dates from the first use of phosphorus on the match-heads. The old "strike-anywhere" match was first dipped in molten sulphur or wax and then into a mixture containing glue, yellow phosphorus, and one or more compounds rich in oxygen, such as potassium chlorate or red lead. When this mixture is rubbed on any rough surface, the phosphorus burns at the expense of the oxygen of the chlorate, and the flame is communicated to the stick by the sulphur or wax. The chief drawback to the use of these matches is that the constant handling of yellow phosphorus causes the factory workers to contract a loathsome and fatal disease called "phossy-jaw". The use of red phosphorus, which is not poisonous, and the invention of the **safety-match**, have overcome this danger. The head of this match contains no phosphorus at all. It consists of a mixture of antimony sulphide, potassium chlorate, potassium dichromate and glue, and is ignited on a specially prepared surface containing red phosphorus and antimony sulphide.

The danger has also been overcome in the case of the "strike-anywhere" match. In the heads of these, the poisonous yellow phosphorus is now replaced either by a compound of phosphorus and sulphur called phosphorus sulphide or by another allotrope called **scarlet phosphorus.** These substances have no bad effect on the workers.

PRACTICAL WORK

The greatest caution must be taken in performing experiments with phosphorus or serious accidents will occur.

1. **Properties of phosphorus.**—(*a*) Observe the appearance of some ordinary sticks of phosphorus. Notice that it is kept completely covered in water in a bottle. Remove a stick of the phosphorus with a pair of tongs, place it completely under water in a dish, and cut it with a knife ; observe the appearance of the cut surface. Note what happens when phosphorus is exposed to the air in the dark.

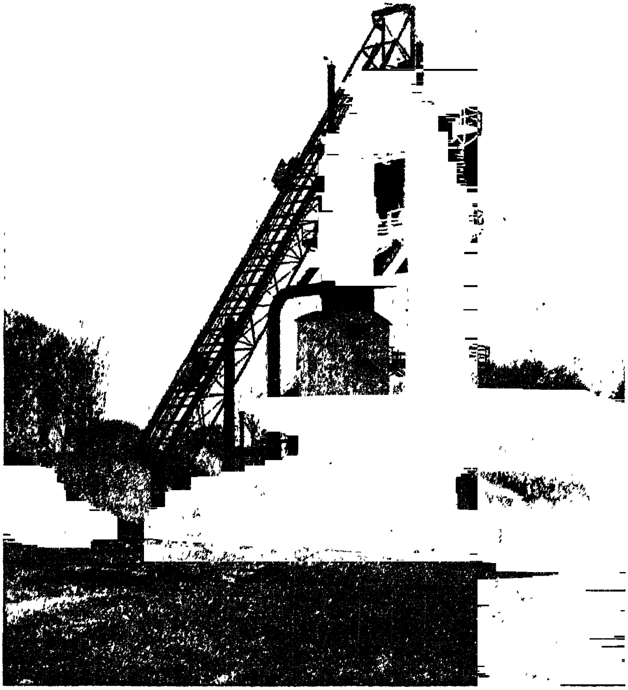
(*b*) Place a very small piece of phosphorus in an evaporating basin containing water, and heat it slowly. Note the temperature at which the phosphorus is seen to melt. Allow it to cool.

2. **Red phosphorus.**—Examine red phosphorus and observe how it differs from the ordinary form. Find whether it can be melted as in Expt 1 (*b*).

NOTE.—*These experiments should be performed by the teacher.*

3. Grind up in a mortar a lump of cane-sugar with an equal quantity of potassium chlorate. Place the mixture on an iron tray and add a drop of strong sulphuric acid on a glass rod. Note that the whole mass inflames violently.

4. Mix thoroughly in a mortar equal *small* quantities of antimony sulphide, potassium chlorate and potassium dichromate. Add to this a little *red* phosphorus. Place the whole mixture on an iron tray. Stir with a *long* glass rod until combustion takes place.



Priest Furnaces, Ltd.

FIG. 230.—A modern continuous lime kiln.

mass porous, so that the carbon dioxide can penetrate below the surface.

Cement is made by roasting a mixture of limestone and clay, the latter being a compound of aluminium and sand or silica. It is a grey powder which has been ground until it is as fine as flour. When mixed with three or four times as much sand, and made into a paste with water, it sets to a hard mass, probably owing to the formation of compounds of calcium with silica, known as silicates.

Concrete is a mixture of cement and broken stones and gravel or sand. Houses, bridges and similar structures are often built of

concrete, strengthened by a lattice framework of thin iron rods; wooden moulds are built up around this lattice work, and the concrete is poured in and allowed to set, after which the mould boards are removed. It is then called **reinforced concrete.**

Mild and caustic alkalis.—When caustic soda is dissolved in water, the solution feels slimy and it will neutralise an acid, forming a salt. A solution of washing-soda similarly feels "soft" and will neutralise an acid, again forming a salt, but effervescence occurs as a gas, carbon dioxide, is given off. This similarity in their properties has led to their being classed together as **alkalis.** Other alkalis are caustic potash and potash. Washing-soda and potash are known as **mild alkalis**, whereas caustic soda and caustic potash are termed **caustic alkalis**, because their alkaline properties are more intense.

By boiling a solution of soda with slaked lime, the mild alkali is converted into caustic soda:

$$Na_2CO_3 + Ca(OH)_2 = 2Na(OH) + CaCO_3.$$

Caustic soda.—Caustic soda, or sodium hydroxide as it is often called in the laboratory, can be made as mentioned above, by boiling soda with slaked lime. The resulting solution is filtered, evaporated, and the caustic soda fused in iron pans.

In another process, which is growing in importance, it is manufactured by the electrolysis of a solution of common salt. A Castner-Kellner cell is used, and the products are gaseous chlorine from the anode and a solution of caustic soda at the cathode. The process is described in discussing the manufacture of chlorine (p. 269). The solution of caustic soda is evaporated to dryness, and the caustic soda fused and cast into sticks.

Caustic soda is a white solid which when exposed to the atmosphere absorbs moisture readily, forming a saturated solution. The latter absorbs carbon dioxide, producing sodium carbonate (washing-soda), which solidifies, protecting the stick of caustic soda from further deterioration. Caustic soda attacks the skin very quickly, so it should not be handled. Solutions of it are powerfully basic and will slowly corrode even glass. It is largely used in the manu-